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XIV International Conference on Mathematics, Science and Technology Education

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XIV International Conference on Mathematics, Science and Technology Education

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Abstract. This paper represents a preface to the Proceedings of the XIV International Conference on Mathematics, Science and Technology Education (ICon-MaSTEd 2022) held at the Kryvyi Rih State Pedagogical University, Ukraine, 18–20 May 2022. Background information and the organizational structure of the meeting, proceedings structure, and acknowledgments of the contributions of the many people who made the conference a success are presented.

1. Background

The **International Conference on Mathematics, Science and Technology Education** (**ICon-MaSTEd**) is a peer-reviewed international conference, which covers research on mathematics, science and technology education, along with technology-enhanced learning, including blended learning, E-learning, ICT-based assessment, mobile learning, etc. (figure 1)

Since 2001, ICon-MaSTEd is the premier interdisciplinary forum for social scientists, academicians, researchers, professionals, policymakers, postgraduate students, and practitioners to present their latest research results, ideas, developments, and applications [1–3]. There is an urgent general need for principled changes in mathematics, science and technology education elicited by promising theories, models, tools, services, networks, and communications.

There were 94 submissions received. Each submission was reviewed by at least 3 program committee members. The committee decided to accept 42 papers.

The spread of the coronavirus that causes COVID-19 and the ongoing Russian invasion of Ukraine (figure 2) has changed the conference organization. Therefore, the XIV International

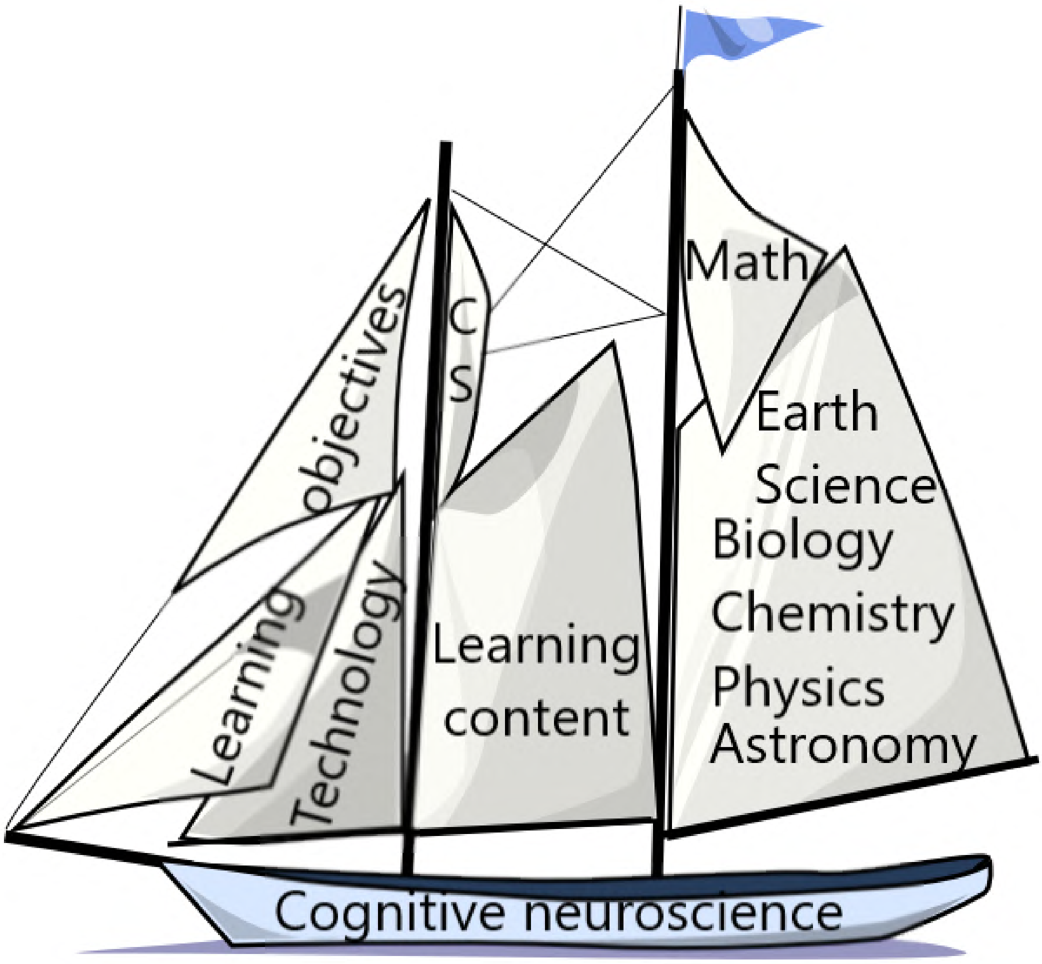

Figure 1. ICon-MaSTEd logo.

Conference on Mathematics, Science and Technology Education (ICon-MaSTEd 2022) took place on 18–20 May 2022 at the Kryvyi Rih State Pedagogical University, Ukraine, both in-person and online.

More than 100 attendees from 7 countries are joined to ICon-MaSTEd 2022 using Zoom. The conference featured invited and contributed talks in a wide number of subject areas: Computer Science and Computer Science Education, Biology and Biology Education, Chemistry Education, Mathematics Education, Physics and Physics Education, Integrated Science Education, Educational Technology and Technology Education.

The presentation slots were defined as follows:

- invites talks (30 min): 20 min presentation, 10 min question answering and discussion,
- other talks (20 min): 15 min presentation and 5 minutes question answering and discussion.

The full program is available at the `https://icon-masted.easyscience.education/2022/` where details of the sessions, usually headed by one or more invited presentations. Video records of talks are available at the *Not So Easy Science* YouTube channel (`https://www.youtube.com/watch?v=oPwFXHZMKV8&list=PL99Jr1_pixpNlmTj2h6NU97fH9GQ72qfT`).

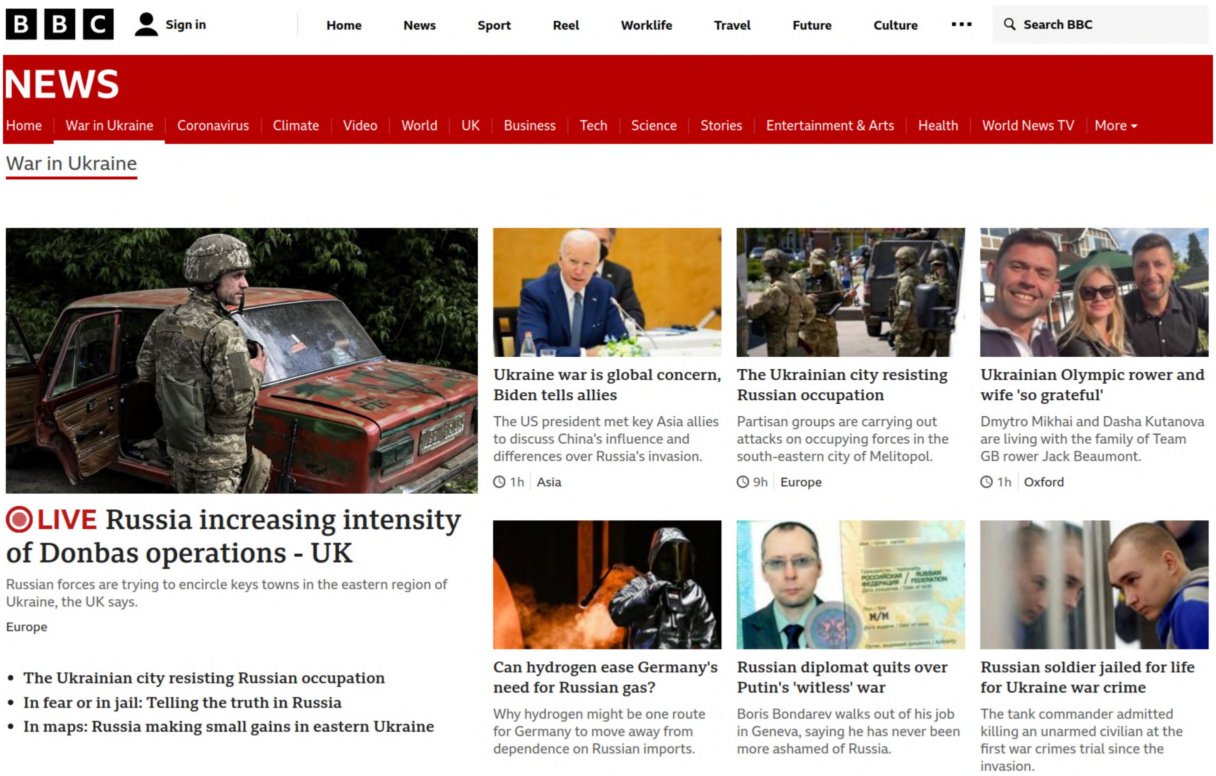

Figure 2. BBC on the War in Ukraine (`https://www.bbc.com/news/world-60525350`).

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3. Proceedings structure

(i) Computer Science and Computer Science Education [4–15]
(ii) Biology and Biology Education [16–19]
(iii) Chemistry Education [20–22]
(iv) Mathematics Education [23–28]
(v) Physics and Physics Education [29–33]
(vi) Integrated Science Education [34–38]
(vii) Educational Technology and Technology Education [39–45]

4. Conclusion

XIV installment of ICon-MaSTEd was organized by the Academy of Cognitive and Natural Sciences (`https://acnsci.org`) in collaboration with Kryvyi Rih State Pedagogical University, Ukraine (with support of the rector Prof. Yaroslav Shramko), Kryvyi Rih National University, Ukraine (with support of the rector Prof. Mykola Stupnik), Institute for Digitalisation of Education of the NAES of Ukraine (with support of the director Prof. Valeriy Bykov) and Ben-Gurion University of the Negev, Israel (with support of the rector Prof. Chaim Hames).

We are thankful to all the authors who submitted papers and the delegates for their participation and their interest in ICon-MaSTEd as a platform to share their ideas and innovation. Also, we are also thankful to all the program committee members for providing continuous guidance and efforts taken by peer reviewers contributed to improving the quality of papers provided constructive critical comments, improvements, and corrections to the authors are gratefully appreciated for their contribution to the success of the conference. Moreover, we would like to thank the developers of Morressier, who made it possible for us to use the resources of this excellent and comprehensive conference management system, from the call of papers and inviting reviewers, to handling paper submissions and creating the volume of the conference proceedings. Special thanks to session chairs for their work on the conference and its program, excellent and gratefully appreciated conference support.

We are looking forward to excellent presentations and fruitful discussions, which will broaden our professional horizons. We hope all participants enjoy this conference and meet again in a

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more friendly, hilarious, and peaceful further ICon-MaSTEd 2023. The next meeting in the series is the XV International Conference on Mathematics, Science and Technology Education, 2023, Kryvyi Rih, Ukraine (`https://icon-masted.easyscience.education/2023/`).

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Peer Review Statement

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Peer Review Statement

All papers published in this volume have been reviewed through processes administered by the Editors. Reviews were conducted by expert referees to the professional and scientific standards expected of a proceedings journal published by IOP Publishing.

- **Type of peer review:** Double Anonymous
- **Conference submission management system:** Morressier
- **Number of submissions received:** 94
- **Number of submissions sent for review:** 69
- **Number of submissions accepted:** 42
- **Acceptance Rate (Submissions Accepted / Submissions Received × 100):** 44.7
- **Average number of reviews per paper:** 3
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Algorithm of ant colony optimization (ACO) for 3D variation traveling salesman problem

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Algorithm of ant colony optimization (ACO) for 3D variation traveling salesman problem

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Abstract. The article discusses the solution of the spatial traveling salesman problem (TSP 3D variation) using Ant Colony Optimization (ACO). The traveling salesman problem considers n bridges and a matrix of pairwise distances between them. It is necessary to find such an order of visiting cities so that the total distance traveled was minimal, each city was visited exactly once and the salesman returned to the city from which he began his route. In the TSP 3D variation problem, each "city" has 3 coordinates x, y, z. The analysis of the main methods of solving, in particular, the metaheuristic algorithms to which ACO belongs, is performed. At each iteration of these methods, a new solution of the problem is built, which is based not on one, but several solutions of the population. The ACO uses an idea that is based on collecting statistical information about the best solutions. The program code is implemented in MATLAB. During computational experiments, various network topologies were randomly generated, and the number of iterations at which the optimal cycle was achieved was recorded. The execution time of the code for the TSP 3D task is almost the same as the execution time of TSP 2D. The results can be used for spatial tasks of the salesman (TSP 3D-variation), which arise in the process of 3D printing, planning UAV trajectories (UAV) in mountain conditions or multi-story urban development, road planning in multi-story buildings.

1. Introduction

The traveling salesman problem considers n bridges and a matrix of pairwise distances between them. It is necessary to find such an order of visiting cities so that the total distance traveled was minimal, each city was visited exactly once and the salesman returned to the city from which he began his route. In other words, in a weighted complete graph, you need to find the Hamiltonian cycle of minimum weight.

The traveling salesman problem occupies a special place in combinatorial optimization and operations research. Historically, it was one of the tasks that gave impetus to the development of these areas. The simplicity of formulation, finiteness of the set of admissible solutions, clarity, and, at the same time, colossal costs for a complete search still push mathematicians to develop new numerical methods. All new ideas are first tested on this task. The most important generalization of the traveling salesman problem for transport and logistics, that several vehicles with limited capacity must serve customers by visiting them in the specified time windows. The traveling salesman problem is left with only a combinatorial essence, a purely mathematical problem that has not been solved for half a century.

In the modern world, the need to solve combinatorial optimization problems is growing every day. Drawing up an optimal schedule for the operation of industrial units, building the shortest road network between given objects, finding the minimum length of bypassing settlements - all these tasks require the most efficient solution. One of the classic combinatorial optimization problems is the traveling salesman problem. Its essence is to find the most profitable Hamiltonian cycle - a route that passes through all given cities once and then returns to the original city.

The ideas of the local search were further developed in metaheuristics, ie in general schemes for constructing algorithms that can be applied to almost any discrete optimization problem. All metaheuristics are iterative procedures, and for many of them, there is an asymptotic convergence of the best solution to the global optimum. Unlike algorithms with estimates, metaheuristics are not tied to the specifics of the problem. These are general iterative procedures that use randomization and elements of self-learning, search intensification and diversification, adaptive control mechanisms, constructive heuristics, and local search methods. Metaheuristics include Genetic Algorithms (GA), Evolutionary Computation (EC), Tabu Search (TS), Simulated Annealing (SA), Greedy Randomized Adaptive Search Procedure (GRASP), Ant Colony Optimization (ACO), and others [1]. The idea of these methods is based on the assumption that the objective function has many local extremes, and it is impossible to review all permissible solutions, despite the finiteness of their number. In such a situation, it is necessary to focus the search on the most promising parts of the eligible area. Thus, the task is to identify such areas and quickly review them. Each metaheuristic solves this problem in its way.

Metaheuristics are divided into trajectory methods, where each iteration has one valid solution and the transition to the next, and methods that work with a family (population) of solutions. The first group includes TS, SA, VNS. Trajectory methods leave in the search space a trajectory, a sequence of solutions, where each solution is adjacent to the previous one concerning some neighborhood. In the TS, SA methods, the environment is determined in advance and does not change during operation. The target function changes non-monotonically along the trajectory, which allows you to get out of the local extremes and find all the best approximate solutions.

Elements of self-adaptation allow you to change the parameters of algorithms using search history. More sophisticated methods, such as VNS, use multiple neighborhoods and change them systematically to diversify. When the environment changes, the landscape changes. Conscious change of landscape, as, for example, in the noise method, has a positive effect on search results. The study of landscapes, their properties, such as ruggedness allows giving recommendations on the choice of neighborhoods.

The second group of methods includes GA, EC, ACO, and others. At each iteration of these methods, a new solution of the problem is built, which is based not on one, but several solutions of the population. Genetic and evolutionary algorithms use crossover and targeted mutation procedures for this purpose.

ACO methods use a different idea, which is based on collecting statistical information about the most successful solutions. This information is taken into account in probabilistic greedy algorithms and suggests which components of the solutions (graph ribs) most often led to a small error in the past. The methods of this group are usually based on analogies from wildlife. The idea of ACO is an attempt to imitate the behavior of ants, which have almost no vision and focus on the smell left by predecessors. A substance with a strong odor - a pheromone - is an indicator of the activity of precursors. It accumulates the prehistory of the search and resembles the road to the anthill.

Attempts to spy out the methods of solving difficult combinatorial problems in nature are finding new incarnations in numerical methods. For example, when infected, the body tries to find (generate, construct) the most effective protection. Observation of this process led to the birth of a new method - artificial immune systems. The study of the activity of the beehive, where only one uterus leaves offspring, was the basis of new genetic methods. However, the greatest progress has been made in hybridization, for example, the construction of heuristics that automatically select the most effective heuristics for this example and symbiosis with classical methods of mathematical programming.

In our time, the traveling salesman problem (TSP 3D-variation) has gained new applications. For example, in the process of 3D printing, there is a need to minimize the transitions of the printhead from the endpoint of the path to the starting point, which reduces the deteriorating print quality. The endpoints of the line segments can be considered as "cities" in the transformation of the problem of minimizing the number of transitions to the traveling salesman problem [2].

The problem of UAV trajectory optimization is also related to the two existing common classic tasks - the salesman and the transport problem. For all UAV applications, one of the main problems "is the choice of paths and trajectories, because UAVs have limited energy, limited load capacity, and are vulnerable to difficult weather conditions" [3]. The problem of three-dimensional UAV path planning (UAV) arises when it is necessary to plan traffic in mountain conditions, or in multi-story urban development [4].

With the increasing complexity of indoor living environments, there is a growing need to optimize indoor navigation. Currently, indoor "navigation path options are monotonous, as existing navigation systems usually offer the shortest or fastest paths from a single starting point" [5]. Such path options may not always be attractive. For example, shoppers in a mall may be interested in a path that goes through several places, starting and ending in one place. This type of path is similar to the classic traveling salesman problem (TSP), but route planning in a large multi-story shopping center involves a 3D variation of the TSP. Solutions to this problem also have the potential to be used in navigation applications for museums, hospitals, and more [5].

This article aims to use the ant colony optimization (ACO) algorithm for three-dimensional (3D) traveling salesman problem. The tasks of realization of the specified algorithm in MATLAB language, check of efficiency, and testing of the program are solved.

2. Theoretical background

The following formulation of the traveling salesman problem is most often used. We have a list of cities in a particular region and a table of pairwise distances between them. You need to find a closed (starting and ending in the same city) route of a salesman who passes through all cities, who enters and leaves each city once, and has a minimum length.

Consider the combinatorial formulation of the traveling salesman problem. Let $s(1), s(2), s(n)$ be some permutation of the numbers $1, 2, ..., n$. If in the set S_n all substitutions

$$s = \begin{pmatrix} 1 & 2 & \dots & n \\ s(1) & s(2) & \dots & s(n) \end{pmatrix} \tag{1}$$

select the set s_n^1 all complete cycles, the traveling salesman problem can be defined as follows. Let

$$C = \|c_{ij}\| \tag{2}$$

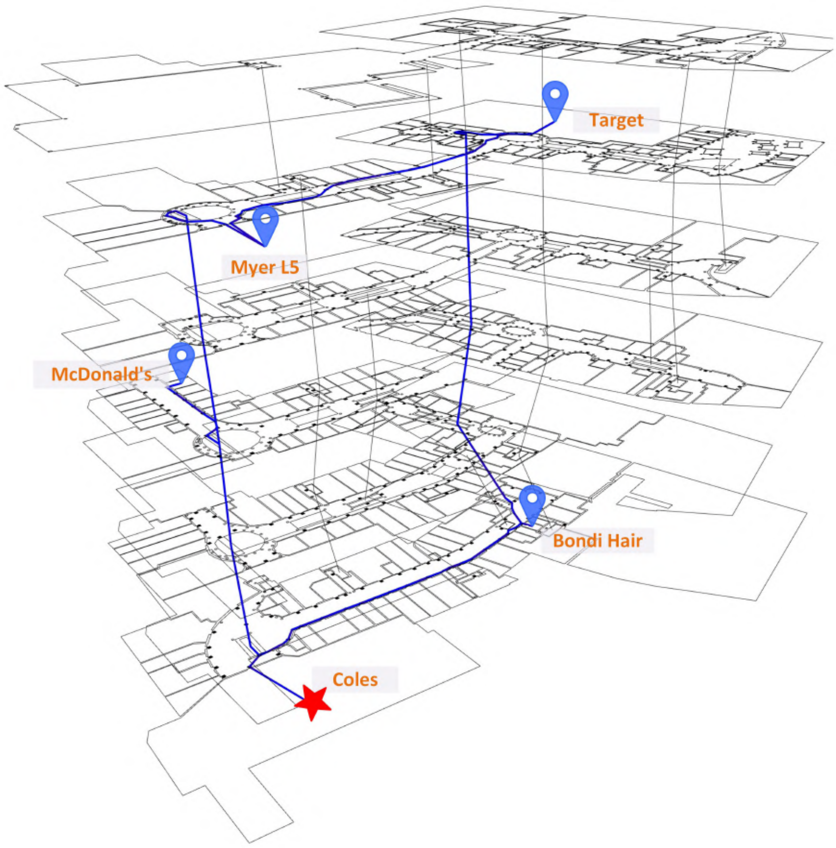

Figure 1. ITSP (Indoor Traveling Salesman Problem) based on multi-story building planning results. The star indicates the place of departure, the location tags indicate the stores that interest the customer (J.Yan et. al, 2021 [5]).

is a $n \times n$ matrix of real numbers, hereinafter referred to as the matrix of distances. Each substitution (1) corresponds to a number

$$L_c(s) = \sum_{i=1}^{n} c_{is(i)} \tag{3}$$

which has the name of the length (more precisely, c-length) of the substitution (1). In particular, if the substitution (1) is a cycle $\tau = (\tau_1, \tau_2, \ldots, \tau_n)$, then its length $L_c(\tau) = (c_{\tau 1 \tau 2}, c_{\tau 2 \tau 3}, \ldots, c_{\tau n \tau 1},)$, (the number n is called the cyclic length of the cycle τ). The traveling salesman problem is to find s_n^1 the substitution (cycle) s_0, for which $L_c(s_0)$ is the minimum on the set of lengths (3), calculated for all complete cycles

$$s_0 = arg\,min\{L_c(s)\}, s \in s_n^1 \tag{4}$$

If the matrix C is symmetric ($c_{ij} = c_{ji}$), then the traveling salesman problem is called symmetric, if C is asymmetric, then the traveling salesman problem will be called asymmetric. If the elements of matrix C is the inequality of the triangle $(c_{ij}) \leq c_{ik} + c_{ki}, i \neq j, i, j, k = \overline{1, n}$, then the matrix C and traveling salesman problem (symmetric or not) is called a metric.

Consider the graphical formulation of the traveling salesman problem. Let $G = (V, A)(G = (V, E))$ – oriented (undirected) graph with many vertices $V(|V| = n)$ and many arcs A (ribs E) $|A| = |E| = m$.

For digraphs, we will use the terms arc, path, contour, for graphs - ribs, chain, loop. All columns are provided without loops and multiple arcs (ribs). The problem is to find the Hamiltonian cycle, ie does the G Hamiltonian cycle exist? The problem of the Hamiltonian chain, the Hamiltonian path, the Hamiltonian circuit is formulated similarly.

Let – $C = \|c_{ij}\| - n \times n$ matrix of arc lengths. Then the asymmetric traveling salesman problem is to determine the Hamiltonian contour of the minimum c-length in the digraph G. Similarly, the symmetrical traveling salesman problem is to determine the Hamiltonian cycle of minimum length in the graph G.

If the vertices of the graph are points of the plane with coordinates x_i and $y_i(i = \overline{1,n})$, then in the main matrix traveling salesman problem the elements of the matrix are determined by the formulas:

$$c_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \qquad \text{(Euclidean metric)} \tag{5}$$

$$c_{ij} = |x_i - x_j| + |y_i - y_j| \qquad \text{(Manhattan metrics)} \tag{6}$$

$$c_{ij} = max\{|x_i - x_j|, |y_i - y_j|\} \qquad \text{(Chebyshev metric)} \tag{7}$$

$$c_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2 + 0.5(x_i - x_j)(y_i - y_j)} \qquad \text{(affine metric)} \tag{8}$$

Elements $c_{ij} = \infty$ in all cases.

In the theory of computational complexity, it is customary to consider recognition problems, ie problems in which the answer may be “Yes” or “No”. For example, is it true that a given graph is a tree? Among the recognition tasks, it is customary to distinguish classes P and NP. Recall that class P consists of recognition problems that are solved in polynomial time. In other words, the number of elementary operations to solve such problems is limited at the top by a polynomial of the length of the input data. The NP class is broader. It includes all recognition problems in which the answer “Yes” can be checked in polynomial time. A problem belongs to this class if, even if you do not know how to solve it, you can easily check the answer by looking at it or finding it on the Internet. It is enough to be able to check only the answer “Yes”. Sometimes checking the “Yes” answer can be easier or harder than checking the “No” answer.

Consider, for example, the problem of the Hamiltonian graph: given a simple undirected graph, you need to know whether it has a Hamiltonian cycle? We show that this problem belongs to the class NP. Suppose the graph is indeed Hamiltonian, and someone gave us an answer by pointing to one of these cycles. The question arises, is it possible to test this clue in polynomial time? To do this, check that the specified set of ribs forms a loop and it covers all vertices. This is easy to do and, therefore, the task belongs to the class NP. Note that the answer “No” is much more difficult to verify here. It is said that the recognition problem belongs to the co-NP class if the answer “No” can be checked in polynomial time.

The problem of determining whether a graph G contains a Hamiltonian cycle or not is an NP-complete problem. In class P, you can check any answer and, therefore, $P \subseteq NP$. A problem of class NP is called NP-complete if the existence of a polynomial algorithm for its solution entails the existence of polynomial algorithms for all problems of class NP. So far no one was able to send in the perfect solution, which is not strange. Today it is one of the central problems of mathematics. Years of intensive research suggest that $P \neq NP$. Indirect proof of this hypothesis is that in the class NP the so-called NP-complete problems are revealed.

In particular, the problem of the Hamiltonian graph is NP-complete. In the traveling salesman problem, you need to find the Hamiltonian cycle of minimum length. This is not a recognition task. It does not lie in the NP class, but it is no simpler than checking the Hamiltonian of a graph. If there is an exact polynomial algorithm for the traveling salesman problem, it is easy to build an exact polynomial algorithm to check the Hamiltonian of the graph. For this purpose it is enough to construct a matrix of distances $C = \|c_{ij}\|$ of the traveling salesman problem according to the following rule according to the graph $G = (V, E)$ which Hamiltonianness is investigated:

$$c_{ij} = \begin{cases} 1, & \text{if } (i,j) \in E \\ 2, & \text{if } (i,j) \notin E \end{cases}, i, j \in V \tag{9}$$

If the solution of the traveling salesman problem has the answer n, then the graph $G = (V, E)$ is Hamiltonian.

The inverse statement is also correct. Problems outside the NP class that are not simpler than NP-complete problems are called NP-difficult. The traveling salesman problem belongs to this class.

The traveling salesman problem has numerous applications.

Meneses S., Cueva R., Tupia M., Guanira M. use a genetic algorithm to find optimal routes in three-dimensional environments (3D variation of TSP). Such evolutionary algorithms are ideal for complex tasks that require restructuring and route optimization [6]. "In the case of genetic algorithms, optimal solutions appear depending on the quality of the original population, so the theory recommends using metaheuristics to generate this population" [6]. Researchers use the GRASP metaheuristic algorithm to generate the initial population and genetic operators to optimize the resulting individuals [6].

S.Mirjalili et. al uses the gray wolf (GWO) algorithm to solve the traveling salesman problem based on the transformation operator (TO-GWO), in which "each wolf represents a possible solution to the TSP and with the help of swap, shift, and symmetry operators and interaction with leader wolves to obtain the optimal solution of TSP" [7]. It is possible to apply the GWO algorithm to the 3D variation of TSP (figure 2).

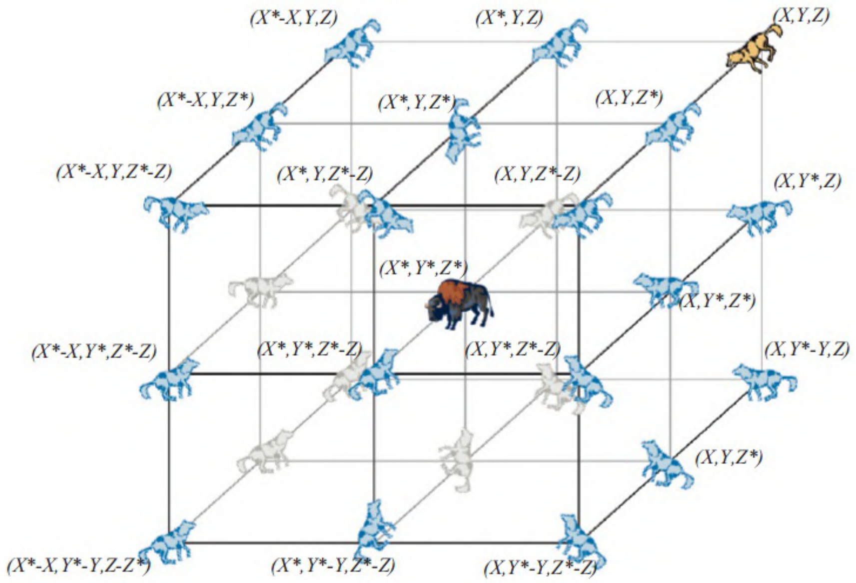

Figure 2. Application of the GWO algorithm for solving the salesman problem (TSP) in 3D (S. Mirjalili et al., 2014 [7]). The wolf in position (X, Y) can update its position according to the position of the victim (X*, Y*) [7].

As already mentioned, the algorithms, which were originally proposed to solve the traveling salesman problem, have been successfully modified to adapt to the problem of obtaining time-saving trajectories for the print head in the process of three-dimensional (3D) printing of many different objects, from toys to high-tech robot parts. The print speed mainly depends on the speed and path of the print attachment. Nuwan C. Ganganath et. al investigate the planning of the trajectory of a 3D printer to increase the speed of the printing process based on the 3D traveling salesman problem [8]. In the work of K.Fok to solve this problem proposed are laxation scheme for a TSP-based 3D printing, path optimizer is proposed [9].

P. Junjie, W. Dingwei apply the algorithm of optimization of ant colonies (ACO) to the multiple traveling salesman problem (MTSP). The results of the calculations show that the proposed algorithm can find competitive solutions in a rational time, even for large-scale problems [10].

M.Mavrovouniotis & S.Yang consider dynamic TSP (DTSP), where cities are replaced by new ones during the execution of the algorithm [11]. In such environments, "traditional ACO algorithms face a serious problem: once they converge, they cannot adapt effectively to changes in the environment. To improve ACO performance on DTSP, hybridized ACO with local search (LS), called the Memetic ACO (M-ACO) algorithm, was used. Simulation experiments on a series of dynamic environments created from a set of reference instances of TSP show that LS is beneficial for ACO algorithms when applied to DTSP because it achieves better performance than other traditional ACO algorithms" [11].

Y.Haxhimusa et. al explored the subjective aspects of the traveling salesman problem. It has been found that when a two-dimensional (2D) traveling salesman problem (TSP) is presented on a computer screen, people can create near-optimal tours in linear time [12]. It is assumed that the deterioration in performance in 3D space can be explained by the geometric relationship between hierarchical clustering in 3D space.

E.Taillard et. al apply metaheuristic partial optimization under special conditions of intensification - POPMUSIC algorithm. It is shown that the POPMUSIC metaheuristics are very effective for the traveling salesman problem. In the process, the algorithm builds a list of the best candidate ribs with a complexity that is less than quadratic. The method has been tested on TSP instances of up to several million cities with different structures (Euclidean uniform, clustered, 2D to 5D, grids, toroidal distances) [13].

The study by H.Yılmaz et. al is aimed at optimizing the cost and operating time of the UAV during demining of the territory after waxing. To solve the problem, the traveling salesman problem was used, which was solved by the method of genetic algorithm for graph nodes placed randomly on a three-dimensional sphere [14].

In the work of I.Gentilini et. al the traveling salesman problem is formulated as a non-convex mixed-integer nonlinear program (MINLP). The global MINLP Couenne optimizer is used to solve the problem. The results of the calculations are represented by polyhedra or ellipsoids in R2 or R3 with the Euclidean norm as a distance metric [15].

The spatial traveling salesman problem (TSP 3D-variation) is investigated in the work of J. Faigl et. al which addresses the problem of planning a multi-purpose path to determine a cost-effective path among a set of three-dimensional regions. This task is one of the variants of the salesman with neighborhoods (TSPN), where a single district consists of several districts, and the task is to determine the shortest multi-purpose route to visit at least one district of each city. Each district, in turn, can consist of several districts. In the scientific literature, this problem is called Generalized TSPN (GTSPN). J.Faigl et. al offer two heuristic algorithms to quickly solve the GTSPN problem. The first algorithm is based on solving TSP, which is further improved by a fast post-processing procedure. The second algorithm is based on a neural network with learning without a teacher - GSOA. The results show that both proposed heuristics provide competitive solutions that are better than the modern reference algorithm for solving the problem of the salesman, but they are two orders of magnitude faster [16].

The first ant colony optimization algorithm (ACO) was proposed in the early 1990s and has since attracted the attention of many researchers, and many successful applications of this algorithm are now available. The most interesting current work concerns the study of the relationship between ACO algorithms and other known methods of stochastic optimization [17]. A significant body of theoretical results is available, which provides useful guidance for researchers and practitioners in the further application of ACO. A detailed review of these results was performed in the work of M. Dorigo et. al [18].

C.Blum & M.Dorigo also offer a new implementation of the ant colony optimization algorithm, called the hypercube framework. In contrast to the usual method of implementing algorithms for optimizing ant colonies, this structure limits the value of pheromones in the range [0,1]. This is achieved by amending the rule of updating the value of pheromones. The experiment shows that, on average, this approach leads to more reliable behavior of the ACO [19].

One of the promising areas is the creation of hybrid metaheuristics. M.Toksari developed a hybrid algorithm based on the ant colony optimization algorithm (ACO) and iterated local search (ILS) [20]. Multiple sequence alignment, known as the NP-complete problem, is one of the most important and challenging tasks in computational biology. It is difficult to solve this type of problem directly to align several sequences, and this always leads to exponential complexity. For example, the hybrid algorithm GA-ACO Z.Lee et. al has been used successfully to align multiple sequences, known as the NP-complete problem in bioinformatics [21]. A hybrid GA and ACO algorithm developed by J. Luan et. al, can be used to solve the multi-criteria problem of choosing a supplier [22].

According to Y.Liu et. al, the way to increase the effectiveness of ACO is primarily to effectively solve the exploration-exploitation dilemma [23].

S.Chaharsooghi et. al proposed "a modified version of ant colony optimization (ACO), which tried to increase the efficiency of the algorithm by increasing the level of training of ants. The effectiveness of the proposed algorithm was confirmed by comparing the result of ACO with the hybrid genetic algorithm (hGA), which was later applied to MORAP - the problem of multi-purpose resource allocation" [24].

ACO has been used "successfully to solve the problem of detecting image edges. The proposed ACO-based edge detection approach can establish a pheromone matrix that represents the edge information presented at each pixel position of the image, according to the movement of ants in the image" [25]. T.Qasim et. al propose an ACO-based structure for WSN deployment in a realistic 3-D environment by modifying the standard ACO algorithm [26].

Route planning is one of the most important issues in the development of autonomous submarines. To solve this problem X.Yu et. al developed a two-layer hybrid algorithm ACO-A*, by combining the optimization of ant colonies (ACO) with the search for A* [27].

Thus, we can see the widespread use of ACO in various fields, which indicates its effectiveness and versatility.

3. Research methods

In this paper, we propose the use of the Ant Colony Optimization (ACO) algorithm to solve the spatial problem of a salesman (3D variation of TSP).

The ant colony method can be applied to any combinatorial problem that can be consistent with the following requirements. Appropriate representation of the problem: the solution space should be represented as a graph with a set of vertices and edges between the vertices; a correspondence must be established between the solution of the combinatorial problem and the route in the graph. It is necessary to develop rules (methods): initial placement of ants at the vertices of the graph; construction of feasible alternative solutions (route in a graph); a rule that determines the probability of an ant moving from one graph vertex to another; the rule for updating pheromones on the edges (vertices) of the graph; pheromone evaporation rule.

Ants use two methods of transmitting information: direct - food exchange, mandibular, visual, and chemical contacts, and indirect - stigmergy. Stigmergia is a time-varying type of interaction, in which one subject of the interaction changes some part of the environment, and others use information about its state later when they are near it. Biologically, stigmergia is carried out through a pheromone - a special secretion that forms a trail when moving ants. Pheromone is a fairly stable substance, it can be perceived by ants for several days. The higher the concentration of pheromone on the trail, the more ants will move on it. Over time, the pheromone evaporates, allowing ants to adapt their behavior to changes in the environment. The distribution of the pheromone by the path of ants is a kind of dynamic variable of the anthill's global memory. Any ant can perceive and change only one local cell of this global memory at a fixed point in time.

Ant colony optimization algorithm is based on the simulation of natural mechanisms of self-organization of ants, the use of which will be considered on the example of optimizing the route of the salesman. Traveling Salesman Problem is to find the most profitable route that passes through these cities at least once. The multiplicity of interaction is realized by the iterative search of the route of the salesman by several ants at the same time. In this case, each ant is considered as a separate, independent salesman who solves his problem. For one iteration of the algorithm, each ant carries out the full route of the salesman.

Positive feedback is realized as an imitation of the behavior of ants such as "leave tracks - move on the tracks." The more traces left on the trail - the ribs of the count in the task of a salesman, the more ants will move on it. At the same time, new tracks appear on the trail, which attracts additional ants. For the traveling salesman problem, positive feedback is realized according to the following stochastic rule: the probability of including the rib of the graph in the route of the ant is proportional to the amount of pheromone on it. The application of this rule ensures the implementation of another component of the program of self-organization - chance, which is implemented by the function of "roulette wheel".

A pheromone is a specifically chemical substance that determines the interaction between ants, which deposit this substance on the path traveled. When choosing a path, the ant does not take only the fact of a short path, but also takes into account the experience of other ants, this information, the ant receives from pheromones on each path. It turns out that pheromones determine the desire of the ant to make a choice between one or another route. Although with this approach, it is impossible to avoid falling into the local optimum. This emerging problem is solved with the help of pheromone vapors.

Using only positive feedback leads to premature convergence of solutions - to the case when all the ants are moving on the same suboptimal route. To avoid this, negative feedback is used - pheromone evaporation. The evaporation time should not be too long, as there is a risk of the population of the routes converging to a single suboptimal solution. On the other hand, the evaporation time should not be too short, because it leads to rapid "forgetting", memory loss of the colony, and, consequently, to uncooperative behavior of ants. In the behavior of ants, co-operation is very important: many identical ants simultaneously explore different points in the solution space and pass on their experience through changes in the anthill's global memory cells.

For each ant, the transition from city i to city j depends on three components: the memory of the ant (taboo list), visibility, and the virtual trace of the pheromone.

Tabu list (ant memory) is a list of cities visited by ants, which can not be visited a second time. Using this list, the ant is guaranteed not to get into the same city twice. It is clear that the taboo list grows during the route and is reset at the beginning of each iteration of the algorithm. Denote by $J_{i,k}$ the list of cities that still need to visit the ant k, located in the city i. It is clear that $J_{i,k}$ is an addition to the taboo list.

Visibility is a value that is inverse to the distance: $\eta_{ij} = 1/D_{ij}$ where D_{ij} is the distance between cities i and j. Visibility is local static information that expresses a heuristic desire to visit city j from city i - the closer the city is, the greater the desire to visit it. Using visibility alone, of course, is not enough to find the optimal route.

The virtual trace of the pheromone on the rib (i, j) is confirmed by the experience of ants' desire to visit the city j from the city i. In contrast to visibility, the pheromone footprint is more global and dynamic information - it changes after each iteration of the algorithm, reflecting the experience gained by ants. The amount of virtual pheromone on the rib (i, j) on the iteration t is denoted by $\tau_{ij}(t)$.

An important role in ant algorithms is played by the probability-proportional rule, which determines the probability of transition of the k-th ant from city i to city j on the t-th iteration:

$$\begin{cases} P_{ij,k}(t) = \frac{[\tau_{ij}(t)]^{\alpha}\cdot[\eta_{ij}]^{\beta}}{\sum_{l\in J_{j,k}}[\tau_{ij}(t)]^{\alpha}\cdot[\eta_{ij}]^{\beta}}, & \text{if } l \in J_{j,k} \\ P_{ij,k}(t) = 0, & \text{if } l \notin J_{j,k} \end{cases} \tag{10}$$

where α and β are two parameters that determine the weight of the pheromone trace and visibility when choosing a route. At $\alpha = 0$, the nearest city will be chosen, which corresponds to the greedy algorithm in the classical optimization theory. If $\beta = 0$, then only pheromone amplification works, which leads to rapid degeneration of routes to a single suboptimal solution. Note that rule (1) determines only the probabilities of choosing a city.

The choice of the city is based on the principle of the "roulette wheel": each city has its sector with an area that is proportional to the probability (10). To select a city, you need to throw a ball at roulette - generate a random number, and determine the sector in which the ball will stop. Note that although rule (10) does not change during the iteration, the values of the probabilities $P_{ij,k}(t)$ for two ants in the same city may differ, because $P_{ij,k}(t)$ is a function of $J_{i,k}$ is a list not yet visited cities by ants k.

There are three variants of the ant system algorithm AS, which differ in the method of calculation $\Delta\tau_{ij,k}(t)$. In the first variant of the ant cycle algorithm, after the completion of the route, each ant k deposits the amount of pheromone on the rib (i, j):

$$\Delta\tau_{ij,k}(t) = \begin{cases} \frac{Q}{L_k(t)} & \text{if } (i,j) \in T_k(t) \\ 0, & \text{if } (i,j) \notin T_k(t) \end{cases} \tag{11}$$

where $T_k(t)$ is the route taken by the ant k in the iteration of t; $L_k(t)$ is the length of this route; Q is an adjustable parameter, the values of which are chosen in the same order as the length of the optimal route. To implement the ant cycle, the contribution of pheromones is inversely proportional to the quality $L_k(t)$ of the complete path that the ant has built. Global information is used to update the pheromone concentration, Q is a positive constant.

The second option - the algorithm "density of ants"

$$\Delta\tau_{ij,k}(t) = \begin{cases} Q & \text{if } (i,j) \in T_k(t) \\ 0, & \text{if } (i,j) \notin T_k(t) \end{cases} \tag{12}$$

Each ant deposits the same amount of pheromones on each link of the constructed path. This approach greatly simplifies the counting of the number of ants following the link (i, j). The higher the density (intensity) of movement on the link, the more desirable that the link was part of the final solution.

The third option - "the number of ants"

$$\Delta\tau_{ij,k}(t) = \begin{cases} \frac{Q}{d_{ij}} & \text{if } (i,j) \in T_k(t) \\ 0, & \text{if } (i,j) \notin T_k(t) \end{cases} \tag{13}$$

In this case, only local information d_{ij} is used to restore the pheromone concentration. Links with lower costs are becoming more desirable. If d_{ij} is the distance between nodes, then the "number of ants" algorithm prefers the choice of the shortest connections.

To study the entire solution space, it is necessary to ensure the evaporation of the pheromone - a reduction in the amount of pheromone that was deposited in previous iterations. Let us denote the evaporation coefficient of the pheromone by $p \in [0, 1]$. Then the pheromone update rule will take shape

$$\tau_{ij}(t+1) = (1-p) \cdot \tau_{ij}(t) + \Delta\tau_{ij}(t), \tag{14}$$

where $\tau_{ij}(t) = \sum_{k=1}^{m} \Delta\tau_{ij,k}(t)$, m - the number of ants in the colony.

At the beginning of the optimization, the amount of pheromone is assumed to be equal to a small positive number τ_0. The total number of ants in the colony remains constant during the execution of the algorithm. Numerous colonies lead to a rapid increase in suboptimal routes, and when ants are few, there is a risk of losing cooperative behavior due to limited interaction and rapid evaporation of the pheromone. Usually, the number of ants is assigned equal to the number of cities - each ant starts its route from its city.

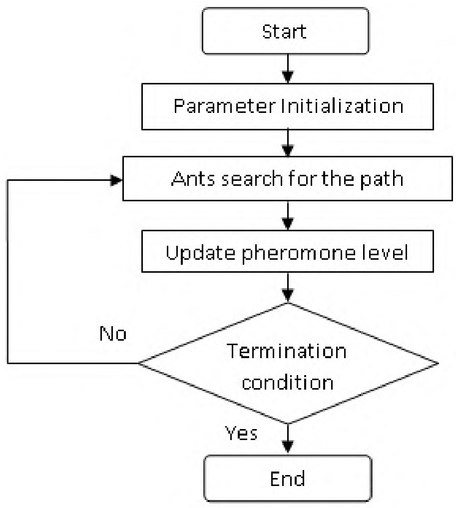

Figure 3. Flow chart of ant colony optimization algorithm.

After the ant path is completed, the ribs are updated according to the path length and the pheromone has evaporated on all faces, the algorithm is restarted. The list of forbidden cities is cleared and the path length is zero. Ants are allowed to move around the network, based on the choice of rib based on equation (10). This process can be performed for a fixed number of paths or until no recurrences have been observed for several runs. Then the best path is determined, which is the solution (figure 3).

Either the achievement of a given number of iterations or the condition when the best of the achieved values of the function F, which is optimized, does not change during a given number of generations is used as a condition for the end of iterations. It should be noted that at present the main attention of researchers is paid to the improvement of swarm algorithms for combinatorial optimization. Most of the modifications for the above ant algorithms are reduced to detailing and refining already successful solutions based on experimental studies.

The paper investigates the application of ACO to solve the problem of a salesman in space. According to the problem, the creation of the initial model involves entering the coordinates of the vertices of the graph (cities). Data were created randomly:

```
x=randi(100,1,20);
y=randi(100,1,20);
z=randi(100,1,20);
```

As mentioned above, if the vertices of the graph are points of the plane with coordinates $x_i y_i (i = \overline{1,n})$ and then in the main matrix traveling salesman problem the elements of the matrix are determined by the formula (5) of the Euclidean metric. For the salesman's spatial problem, the distance matrix will be determined by the formula

$$c_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2 + (z_i - z_j)^2} \tag{15}$$

The distance between the vertices is calculated in a cycle:

```
for i=1:n-1
  for j=i+1:n
     D(i,j)=sqrt((x(i)-x(j))^2+(y(i)-y(j))^2+(z(i)-z(j))^2);
     D(j,i)=D(i,j); %simetric matrix
  end
end
```

4. Results

After the development of the ant colony algorithm to solve the spatial traveling salesman problem, computational experiments were conducted to compare the computing resources needed to solve the 2D and 3D traveling salesman problem.

The number of vertices of the graph (cities) varied in the experiments. During random experiments, different network topologies were generated, and the number of iterations at which the optimal cycle was achieved was recorded. The test was performed on a personal computer with a configuration Intel Core I3 9100 / Gigabyte H310M M.2 2.0 / DDR4 8GB 2400 MHZ / SSD M.2 2280 240GB Kingston / Windows 10.

Table 1 shows the dependence of the time to find the optimal route on the example of randomly generated test graphs with the number of iterations 500.

The execution time of the code for the TSP 3D task is almost the same as the execution time of TSP 2D (figure 4), showing the same proportional dependence of growth after reaching the number of vertices 100.

Visualization of the best rounds was carried out using the functions plot () and plot3 (). It is worth noting that visualization consumed most of the computing resources. Analysis by profiler showed that 71.4% used graphing functions for 2D and 73.1% for 3D tasks on average.

5. Conclusions

The article discusses the solution of the spatial traveling salesman problem (TSP 3D-variation) using the ant colony algorithm (Ant Colony Optimization (ACO)). The task of the salesman in the graph formulation is to find the weighted complete graph of the Hamiltonian cycle of minimum weight. The solution of the salesman's problem can be effectively performed with the help of meta-heuristic algorithms, which can be applied to almost any discrete optimization problem. Metaheuristics of Ant Colony Optimization (ACO) is based on the simulation of natural mechanisms of the self-organization of ants. In this case, each ant is considered as a separate, independent salesman who solves his problem. For one iteration of the algorithm, each ant carries out the full route of the salesman. Positive feedback is realized as an imitation of the behavior of ants such as "leave tracks - move on the tracks." The more traces left on the trail - the ribs of the count in the task of a salesman, the more ants will move on it. The code of the algorithm for solving the spatial traveling salesman problem was developed

Table 1. Results of the ACO algorithm for solving the traveling salesman problem.

Test number	Number of vertices	Length of the best tour (TSP 2D)	Execution time (TSP 2D), s	Length of the best tour (TSP 3D)	Execution time (TSP 3D), s
1	20	371.0264	35.829720	559.2918	38.154607
2	35	508.962	36.824736	913.9878	38.097380
3	50	653.7695	36.372479	1230.6158	38.361924
4	60	676.8418	36.404877	1402.1868	39.490778
5	70	702.5867	36.813301	1498.5958	40.151377
6	85	867.7187	35.911461	1740.9525	39.682652
7	100	900.7155	37.989325	1927.7832	37.599529
8	120	992.564	39.829625	2248.1361	41.069472
9	130	1050.2935	42.871522	2436.3382	43.386317
10	145	1077.1144	46.217642	2553.5011	47.253127
11	160	1143.5688	50.166648	2775.2718	51.089506
12	170	1193.9586	53.364211	3031.8824	53.842818
13	185	1382.8623	55.989983	3012.0454	57.481133
14	200	1390.8527	59.799030	3256.9691	61.367994
15	220	1469.4831	67.857077	3549.5523	66.996831

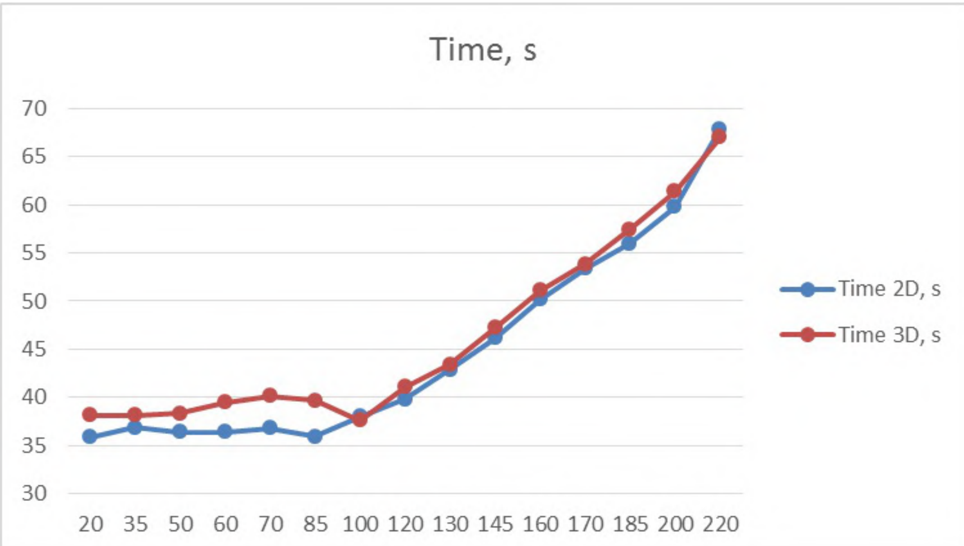

Figure 4. Comparison of ACO algorithm execution time results for solving 2D and 3D traveling salesman problem.

in MATLAB. Computational experiments were conducted to compare the computing resources needed to solve the 2D and 3D problems of the salesman. The results showed that the execution of the code for the TSP 3D task is almost no different from the execution time of TSP 2D. The results can be used for spatial tasks of the salesman (TSP 3D-variation), which arise when it is necessary to minimize the transitions of the print head of the 3D printer, optimize UAV trajectories (UAV) in mountainous conditions or multi-story urban development, road planning

Figure 5. Comparison of the best rounds for solving 2D and 3D traveling salesman problem.

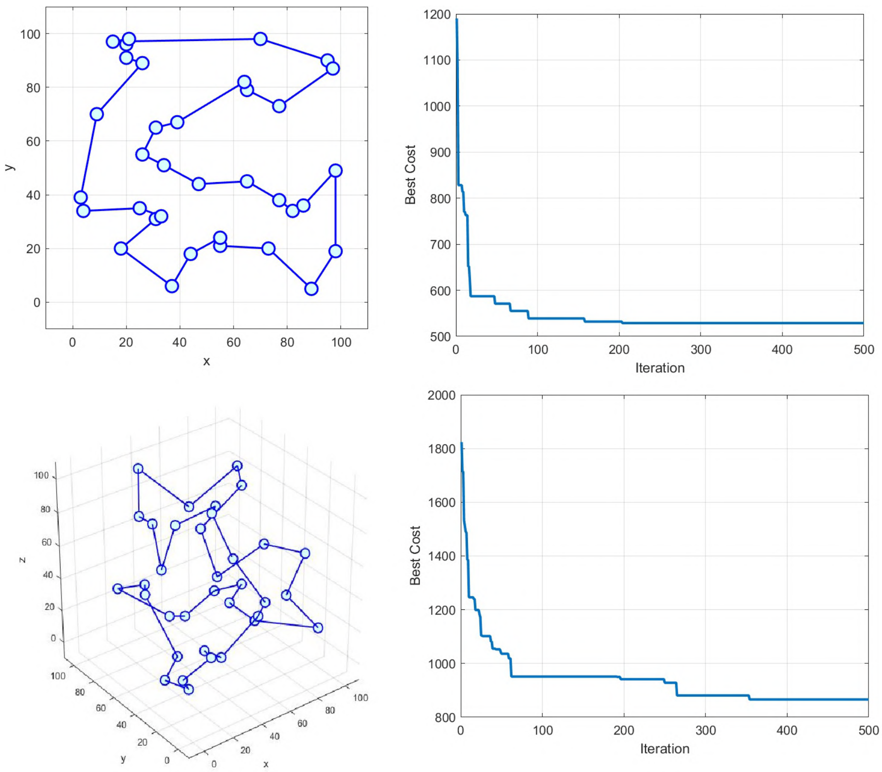

Figure 6. The best tours for 2D and 3D TSP and the dependence of the length of the best tour on the number of iterations.

in multi-story buildings and others.

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Review of state of computer vision technologies development in the world and Ukraine

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Abstract. Computer Vision is a multidisciplinary field, a unit of artificial intelligence and machine learning. It includes the specialized methods and general learning algorithms use. More and more scientists are becoming interested in Computer Vision researching. Therefore, it is important to train future professionals in this area and develop special study programs. We reviewed the development of Computer Vision technologies in the world and in Ukraine, considered the challenges facing professionals and gave an example of Computer Vision project development.

1. Introduction

Machine learning, neural networks, artificial intelligence are topics of interest in the last few years. The reason is increasing interest in technologies and their penetration into everyday activities: financing, insurance, anti-fraud, recommendations and forecasts, NLP. Per growing interest, the IT industry is offering more and more quality developments in these areas. Every industry has already tools that use artificial intelligence technologies. For example, Google Smart Search, contextual advertising, mobile applications such as Reface, smart assistants (Siri and Alexa), disease prediction tools, drone production, optimized, personalized treatment recommendations, and marketing and service talk bots, spam filters in e-mail, social media monitoring tools for dangerous content or false news, song or TV show recommendations from Spotify and Netflix, etc. Recently Facebook announced the development of a new meta-universe [1]. The main message was the ability to create three-dimensional space in the meta-universe. It will allow communicate, learn, collaborate and play in ways that go beyond physical space. Microsoft also announced an update to the communication platform [2]. Microsoft has been working on such concepts for several years since the pandemic. In their developments, both companies are actively using neural networks to filter information, augmented reality to form the communication environment, computer vision as an element of VR and AR, artificial intelligence to target content. Also, companies are developing translation and transcription support, for meetings in cyberspace with colleagues from around the world with smaller language barriers. The transition of IT giants to cyberspace provides prospects for further development of artificial intelligence technologies, augmented reality, neural networks etc. The main trend is people-orientation, freedom of location and stability.

Computer Vision is just a part of the popular trend in Deep Learning. Deep learning is part of a broader set of machine learning methods based on learning data representations rather than algorithms. Basic concepts of object recognition: marking, classification, recognition, detection and segmentation. Among the tasks are an image generation, image recognition, self-driving cars, virtual reality and more. The main purpose of the study is to analyze the state of Computer Vision technologies use in the world and in Ukraine and to outline the prospects for their development in education.

2. Purpose and tasks

Every year, Gartner publishes technological trends that affect business. Among such trends are identified, for example [3] (figure 1):

- Data structure - integration and flexibility of data sources should ensure accessibility regardless of the user's location. It will simplify data management and use analytics to create management recommendations;
- Cybersecurity Mesh - data security and relevance are provided by a flexible architecture. It includes various services. They are integrated with each other. It allows identifying objects and using cloud resources efficiently;
- Cloud platforms are technologies allow creating new application architectures. They help to adapt to changes in technology and promote the practice of working together on projects;
- Intelligent decision-making systems - intelligent systems allow to make better decisions in the organization. Learning such systems involves data analysis and tracking;
- AI Engineering - Artificial Intelligence Engineering automates data updates, models and applications to optimize AI delivery [3];
- Autonomous systems are able to manage processes and optimize system performance without human intervention;
- Generative AI builds a solution based on known facts that does not look like the original. It creates new forms and combinations of facts.

Figure 1. Gartner Top Strategic Technology Trends for 2022.

Most of these trends are related to artificial intelligence technologies and machine learning technologies. Others, such as cloud platforms, Data Fabric use these technologies indirectly and are evolving in conjunction with other trends. To analyze the situation in Computer Vision technologies, we analyzed the number of patents in this field. In recent years, the number has increased significantly. Search Computer Vision gives 136,867 results (figure 2). In the period 2016-2019, there was a significant hitch in the number of developments. In the period of the 2019-2021 pandemic, health principles are important and corporations developing technologies for medicine are the leader in the number of developments (table 1).

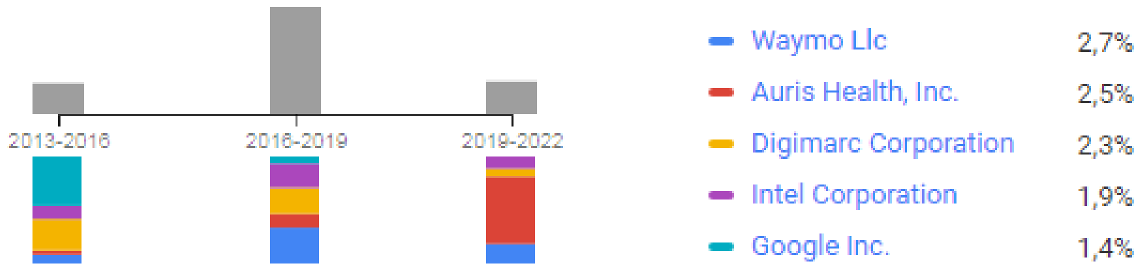

Figure 2. Relative number of Computer Vision patents registered between 2013 and 2021.

The popular research areas are:

- Generative artificial neural networks - image development / processing, video, image overlay, movements. Among the new algorithms is the generation of images by graphs [4]. Segmentation and detection problems for static images have excellent results. New research is trying to solve not only the generation problem, but also generation according to given parameters. However, the navigating tasks in the space of an object or three-dimensional image are still waiting to be solved. In addition, the popular programs are completing or deleting of individual image elements and video. For example, SC-FEGAN [5] allows doing the guided inpaint: the user can complete a part of the face in the erased area of the picture and get a restored picture depending on the picture. Adobe for ICCV combines two GANs: they offer an interactive GAN-based thumbnail translation method that helps novice users to create images of simple objects. The user starts with a sparse sketch and the desired object's category. The network recommends its probable completion and shows the corresponding synthesized image. The user makes an input stroke, and the form generator network gives the multiple form completions based on the selected class. The appearance generator takes one of the completions of the form and creates a realistic image [6]. The KalidoKit library tracks the face, the person's hands. It generates an animation object movements [7].
- Surveillance and visual search systems along with algorithms for identification and recognition of gestures, movements, algorithms for classification and categorization of data have been developed. For example, the Darwin tool automates data labeling provides control over the annotation workflow, and helps identify the data quality issues [8]. The Deepen program makes visual objects tracking [9]. The program's peculiarity is a 3D leader interface for annotation and semantic data segmentation. The separate category is optical character recognition (OCR). The varieties of mathematical algorithms are used, such as statistical correlation, tracking outside, area refinement, mathematical morphology, transformation methods, etc. [10].
- A significant amount of patent work (135,828) is devoted to Robotic Process Automation (RPA) - computer vision in surgical navigation systems, devices for tracking or guiding surgical instruments. Such works are devoted to the control of medical instruments

Table 1. Research areas of the largest corporations in Computer Vision.

Corporation	Number of patents	Research areas
Auris Health, Inc.	187	Emulator motion tracking for medical device control, user interface for medical robotics system, mapping and navigation method and system for medical device guidance, robotic surgical monitoring, etc.
Waymo Llc	1,357	Developments in the field of detection and assessment of barriers on the roads, driving a car, construction of trajectories, detection of weather conditions for driving, avoiding pedestrians, reporting road accidents, etc.
Digimarc Corporation	2,757	Smartphone-based content processing methods and systems, object recognition and related mechanisms, object identification, etc.
Facebook, Inc.	10,978	Visual tracking calibration systems and methods, dynamic eye tracking calibration, gesture-based control system, detection and isolation of objects inside a multimedia object, systems and methods of classification and authentication, identification, etc.
Google Inc.	45,672	Visual search, methods and systems of obtaining input controls of touch sensors and eye recognition, gestures, movements, input systems, user interfaces, etc.
Microsoft Technology Licensing, Llc	91,982	Software ranging of user interface, target positioning with tracking eyesight, stabilizing movement, combining of virtual content into real content, capturing of virtual objects in augmented reality, virtual interaction with image projection, learning image processing tasks from scene reconstructions, etc.
Intel Corporation	95,545	Portable virtual reality, super-resolution visualization, gesture recognition systems and methods, image flow switch.

introduction and / or manipulation, robotic treatment devices and prosthetics. At the same time, the topics of the movement trajectory of devices are studied, for example, in the diagnosis or treatment of the respiratory tract [11], coordination and synchronization between robotic arms in surgical operations [12]. There are also works on evaluation and sorting for grading and sorting plants [13]. Computer vision and machine learning software and algorithms can evaluate and sort plants by desired categories [13]. There are patents devoted to methods for mechanization and automation of cargo movements, for example [14].

- Natural language processing (NLP) and its understanding is relevant. Chat bots use personalized responses to customers of organizations, voice assistants, e-mail that automatically sorts emails etc. Identification of such content includes determining the content relevance [15].

- Ethics of computer vision systems. Data anonymization. Among the topics that come to the fore is the topic of ethics of artificial intelligence. In particular, in object recognition tasks, researchers present programs for recognizing faces and numbers in the crowd. However, there are articles that describe algorithms and technologies that protect ordinary people from unauthorized surveillance. The developers of Facebook present algorithms that level the features of each face and make it unrecognizable to detection algorithms. Google and Microsoft also emphasize the ethics of artificial intelligence and computer vision in particular. They published the principles of construction of AI, its justice

During the pandemic, artificial intelligence technologies and machine learning algorithms received a strong impetus for their development and stopped to be hobbies, brought additional profits to business, and became the hope of inventing drugs and quickly overcoming the pandemic effects [16]. One of the largest free archives of electronic publications of scientific articles arXiv.org has more than eight thousand articles in computer vision. (figure 3) presented their number has grown significantly in recent years - from a few hundred to two thousand a year, and continues to increase.

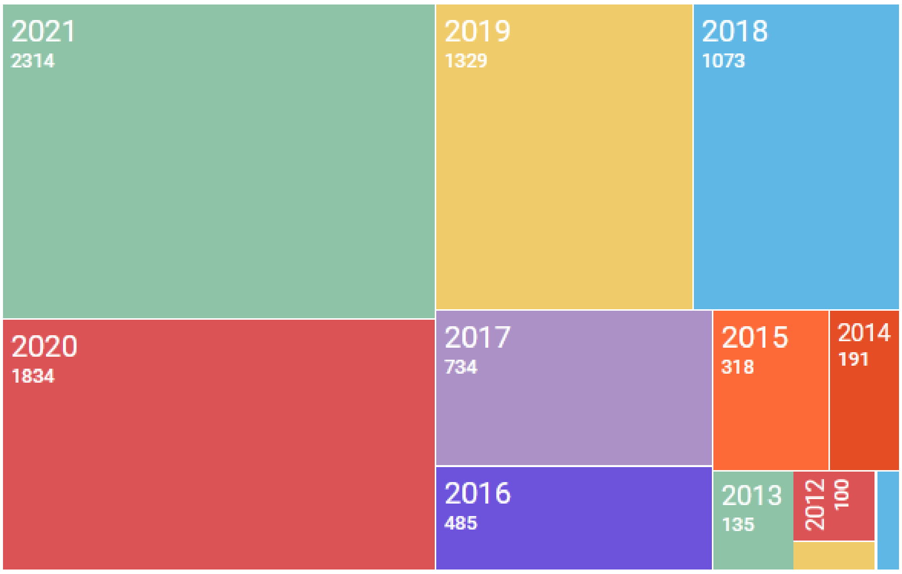

Figure 3. Number of articles in arXiv.org by years.

In addition, the number of conferences and competitions dedicated to Computer Vision has been increased. The kaggle.com platform, a popular machine learning site, has hosted analytics and predictive modeling competitions since 2010. By 2018, only 2 competitions in Computer Vision were hold. But since 2018, competitions are held annually, some events have become annual, such as NYU Computer Vision - CSCI-GA, AU-ECE-CVML2021. The most popular computer conferences in Computer Vision are [17]:

- European Conference on Computer Vision (ECCV).
- International Conference on Machine Learning (ICML).
- Conference on Computer Vision and Pattern Recognition (CVPR).
- British Machine Vision Conference (BMVC).
- International Conference on Computer Vision (ICCV).
- Neural Information Processing Systems (NeurIPS).

Since 2014, a number of conferences dedicated to AI and Computer Vision have been held in Ukraine. About a hundred events have taken place annually in the last five years. However, due to Covid'19, some of them have moved to the online format. These conferences include the Eastern European Computer Vision Conference (EECVC, http://eecvc.com/). It has been operating in Ukraine (Odessa) since 2016 and gathers CV / ML engineers and researchers. Among the top publications, this conference is the second in the world. Last year, more than 600 reports from all over the world were presented. Most of the presented studies are researches in models for vision and learning, optimization of deep learning.

There is the AI Ukraine conference since 2017 to acquaint with the business applications of computer. Developers from around the world present researches in three streams: Data Science and Machine Learning, Big Data and Data Analytics, AI for Business and Products. In 2021, among the presented solutions were:

- Mykola Lavreniuk "Using AI methods to solve the problem of recognizing food and drinks in the canteen (KISSA AI project)"."The KISSA AI project solves the problem of automatic recognition of food and beverages in the canteen with the subsequent automatic calculation of the customer without human intervention";
- Olga Petrova presented a report on image marking methods "Model-assisted data annotation" [18]. She look at some of the approaches of model-assisted data annotation (namely, auto-labeling and active learning) as well as the common use cases that these methods are best suited for;
- Paper Vitaliy Bulygin "Object detection, segmentation and pose estimation for mobile devices" devoted to methods of object detection, segmentation and evaluation of posture for mobile devices and function optimizing of learning losses [19].

Many Ukrainian scientists are working on projects related to the computer vision use in education, expert systems building and practical application A. Chikrii, Y. Kondratenko, V. Gubarev, V. Kuntsevich, O. Berezsky, A. Sachenko and others [**?**, 20–28]. But the most famous project in Ukraine and the world is the startup project Reface, which appeared in 2019 and quickly became popular, attracting the attention of world leaders such as Google. Despite the simplicity of the game arr, a team of Ukrainian developers led by Oles Petriv managed to attract multimillion investments in the project [29]. Another Ukrainian company-developer i3 Engineering deals with smart home systems and devices for automation of hotels, greenhouses, factories, farms, etc. [30].

3. Results and discussion

The development of machine learning and computer vision, in particular, raises a number of issues that need to be solved in the near future: One of them is the introduction of the computer vision study in curricula. Today, there is a need to attract more students to study computer vision. Curricula of neural networks study exist in some universities in computer science specialties [31,32]. Availability of resources (such as OpenCV) allows students to engage in tasks such as image analysis and processing, facial recognition systems, object identification, motion tracking, motion analysis, posture assessment, object identification, image segmentation, video tracking and other. Examples are the tasks of object's movement tracking on a static background (traffic flow tracking) or parking place finding [33]. These works will be related to such topics as deep learning, convolutional neural networks, learning systems, virtual reality, deep neural networks, artificial intelligence. Conventional Neural Networks (CNNs), the Boltzmann family including Deep Belief Networks (DBNs) and Deep Boltzmann Machines (DBMs) and Stacked (Denoising) Autoencoders are the most widely used methods for computer vision tasks [34]. In research [35] shows there is a connection between computer vision, robotics, and educational robots. It can be used to develop computer vision curricula. Such problems are considered in artificial systems theory.

Here is an example of the project developed by students in a virtual environment using computer vision algorithms. The Unity 3D game engine was used to create a virtual environment with the car. This engine was chosen as the simplest and most capable of the car basic mechanics simulating. The camera object was developed and attached to the car model. Python 3 programming language and numpy libraries were chosen for image processing from the camera. Numpy library allows to work faster with multidimensional arrays, opencv has a wide range of tools for CV. The control of a virtual vehicle that moves autonomously on the line was done. To solve the problem of finding the way on the photo, an attempt to create the own algorithm was made. Its advantages will be: speed, accuracy, "foresight" (the algorithm can calculate the path in a few steps ahead). As a result, our own algorithm to find the path to the image from the camera was developed. it works on the sampling principle of the whole path into parts. The algorithm operation can be described by the following steps:

1. Get a color image from the camera and translate into shades of gray.
2. Reduce the image size to speed up the algorithm.
3. Binarization of the image using the adaptive threshold algorithm in order to reduce the lighting impact.
4. Divide the resulting image into horizontal parts with a height of h pixels. The higher the bandwidth, the less likely it is that noise will affect the image.
5. At each part we look for potential segments of the path. The search is performed on the assumption that the width of the path segment should be greater than the next segment.
6. Combine all potential segments into the path tree part by part under the following conditions: the center of the child segment must be within the parent segment; the length of the child segment may be greater than or equal to the length of the parent.
7. In the resulting tree we look for a path that satisfies the following conditions: the number of segments is greater than n; the weighted center of the path segments is closest to the image centre. The algorithm can be easily modified to give priority to the left or right paths.

The result of the developed algorithm, the choice of a certain path at the crossroads, is presented in figure 4. This algorithm provides a fast path search, within 20-30 ms. This algorithm was implemented on a computer model of the car. The virtual model of the car successfully traveled the proposed routes, turning the steering wheel to a certain angle, which was calculated according to the found path.

4. Conclusions and prospects for further research

In this article, we consider the challenges facing world leaders and researchers in the field of computer vision. The number of such studies is growing, and computer vision training methods are being developed. In Ukraine, their number is still small, but the results show that our developers are among the first in the world rankings. Therefore, it is important to create special courses to study the methods of computer vision and implement the practice of teaching methods to future professionals.

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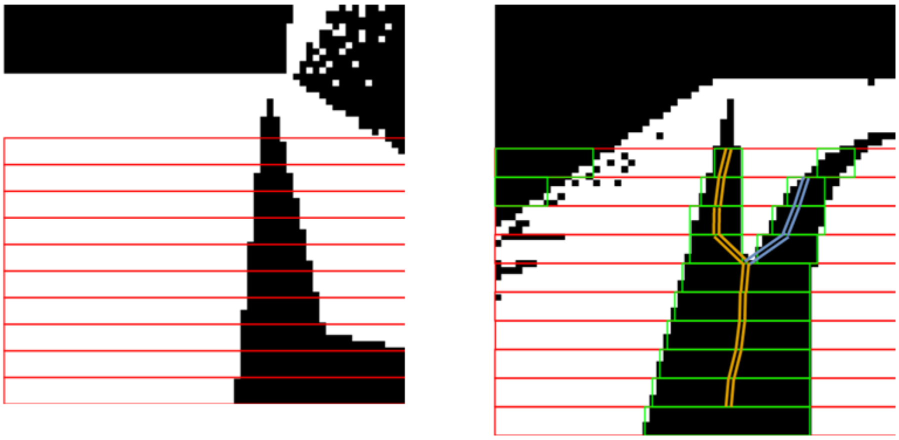

Figure 4. The result of the developed algorithm.

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Application of image processing programs in color analysis of wood photodegradation

Application of image processing programs in color analysis of wood photodegradation

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Abstract. In general, polymer photodegradation is an important aspect of polymer science that is of great interest to chemistry, materials science, biology, and physics students who engage in this field of research. Wood consists of three main polymers, which makes it a good candidate for such photodegradation studies. Aside from structural changes based on chemical analysis, color change assessment can also be employed to check any extent of degradation on wood without the need for sophisticated analytical equipment. This study presents the application of two image processing programs in color analysis of wood photodegradation: *ImageJ* and Colormath library, which are Java-based and Python-based software, respectively. Images of unexposed and UV-exposed wood samples were taken using a smartphone as an affordable digital camera. RGB channel values from these images were analyzed and quantified by *ImageJ* software. These values were converted to the corresponding CIEL*a*b* parameters using the Colormath library to calculate the color change, ΔE. For the 3-hour exposed sample, ΔE is equal to 4.29. This value indicates appreciable color change, according to the criteria from literature. Regardless of the exposure time, the wood samples become darker as indicated by the negative value in the change in lightness L*.

1. Introduction

The Covid-19 pandemic has prompted science educators and students to improvise methods and setups in analyzing various physical phenomena. Image processing programs can be a valuable asset to the researcher, especially for those working from home or to those who do not have access to laboratory equipment. These programs have numerous applications, including the description of basic topography or morphology in quantitative metallography [1]. Other applications include, but are not limited to, the estimation of pathogen concentrations, colorimetric analysis of iron ions in water, and the size measurements of polarized optical microscopy images [2–4]. In a study of wood, however, image processing programs are useful in color analysis to observe any color changes in a given wood type.

Color analysis is crucial in the determination of photodegradation in wood species. Samples are expected to show color changes over a period of ultraviolet (UV) irradiation time [5–7]. For some wood species, this color change is easily observed with the naked eye, while for others it is difficult. Regardless, it is necessary to quantify the results to support the qualitative observations. In practice, it is more common to utilize spectrophotometers in the laboratory, which use CIEL*a*b* measurements. However, it is still possible to measure the same set of data and analyze color changes in a work-from-home setup using image processing programs and a quick conversion to CIEL*a*b* measurements. [8].

ImageJ is a free, online software with multiple functions, one of which is color analysis [9]. The images can be analyzed using the average method or the weighted method depending on the preferences, providing a set of measurements in the RGB scale [10]. Given any possible limitations on the access to spectrophotometers, finances and the ongoing pandemic, *ImageJ* is a useful alternative because it can be done at home and requires no elaborate setup [11]. This program is supplemented with the *Colormath library*, a Python-based library which can convert the RGB values gathered on *ImageJ* into CIEL*a*b* values [12]. This will provide a more detailed analysis on wood photodegradation.

Observing clear and obvious color changes through image processing programs is the first step in indicating possible chemical changes in the wood structure, particularly to its main polymer components: lignin, cellulose and hemicellulose. With the known polymorphs of cellulose, it is cellulose I that is naturally found in wood in parallel strands in the absence of hydrogen bonding [13]. Through chemical analysis later on, the formation of crystallized cellulose I is expected during photodegradation [6]. This indicates the presence of reactions within the wood samples during exposure.

Many experiments on wood photodegradation are conducted using natural sunlight. Results are significant and substantial, although it requires longer time period that can take hundreds of days [14, 15]. Additionally, natural weathering is heavily reliant on the weather conditions, which are not constant and are difficult to control [16]. Artificial weathering is often used as an alternative, wherein wood samples are exposed to a UV laser or UV lamp [17]. Compared to natural weathering, artificial weathering can illustrate color changes immediately within the first few hours, whereas natural weathering generally can take up to a few weeks before observable color changes are visible [18]. While significant, the color changes observed will be supported by further characterization of the wood samples through chemical analysis in Attenuated Total Reflection Fourier Transform Infrared (ATR-FTIR) Spectroscopy.

2. Methodology

Shorea polysperma, commonly known as Tanguile or Tangile, wood samples were cut to a dimension of 6 cm x 6 cm x 1 cm in length, width, and thickness respectively. Afterwards, the edges and sides were smoothened with sandpaper to remove any blisters. The samples were then placed in a clean box to cover it from premature, natural and artificial weathering. The box was covered with a lid and stored in a space away from heat and light.

The wood samples were exposed to a 100-Watt UV germicidal lamp, as depicted in figures 1 and 2, having a quartz tube with peak emission wavelength at 254 nm [19]. Wood samples were exposed at a position 18cm away from the UV lamp tube. The exposure was done at three different time intervals (1, 2, and 3 hours). The samples were placed on a stationary placeholder such that the faces were perpendicular to the beam of UV light. To maintain control of the experiment, artificial photodegradation was conducted at the same time period, from 1:00 to 5:00 PM. No experiments were done during rainy days, both during and before the designated experiment time period. Before and after use, samples were placed in non-transparent plastic containers, to avoid any premature natural and artificial degradation.

A representative UV exposed-sample per batch was chosen consistently for image analysis, on the basis of its proximity relative to the center of the lamp. Before and after exposure, images of the samples were taken using a smartphone as an affordable digital camera. It is important to maintain the same setup for image capture before using the images in *ImageJ* analysis. In a home setup, as shown in figure 3, a tripod was used for stability and extended using a monopod so that it can clamp the camera in place and extend it directly above the sample. A flat surface is recommended to avoid any movement from the sample. Additionally, the background color for image capture should not be similar to the sample. Unless the sample in question is the color

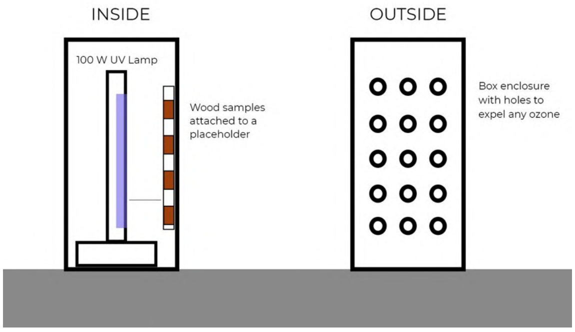

Figure 1. Diagram of the UV photodegradation setup for the wood samples.

Figure 2. Actual placement of samples during testing. The top lid was removed for picture-taking.

white, a regular A4 sheet of paper may be used as the background. Image capture was taken on a mobile phone, using High Dynamic Range (HDR) and no flash. The room lighting was consistent such that a white LED light illuminated the sample from above. Care was taken to remove or cover any possible disturbances to the image capture. Only one image of each sample was necessary before proceeding to image processing.

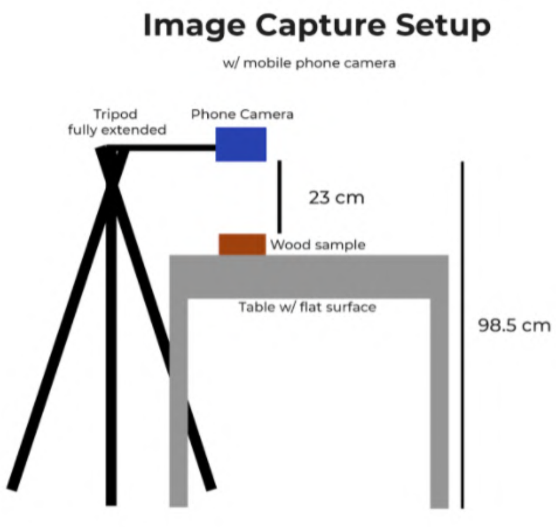

Figure 3. Phone capture setup for wood samples.

Color analysis was first done on *ImageJ* software. Opening this software will display the *ImageJ* console. To analyze a picture of interest, go to File > Open, as depicted in figure 4.

After selecting the picture from a file, the picture will be opened as a new window on *ImageJ*, as in figure 5. An image was split into RGB channels through Image > Color > Split Channels as depicted in figure 6. Three different color images of the wood sample were shown in figures 7.

The macro option was used to ensure that the measurement is taken in the same area. This is done by going to Plugins > Macros > Record, given in figure 8. When the Recorder window

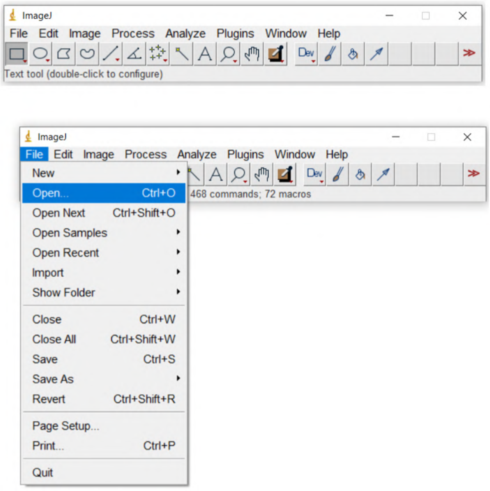

Figure 4. The *ImageJ* console appearance.

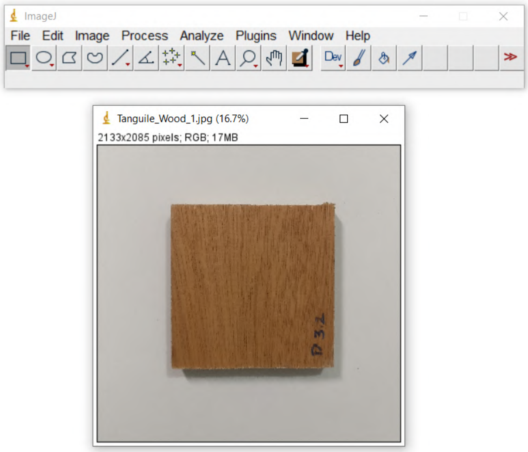

Figure 5. The file appearance as it is opened on the software.

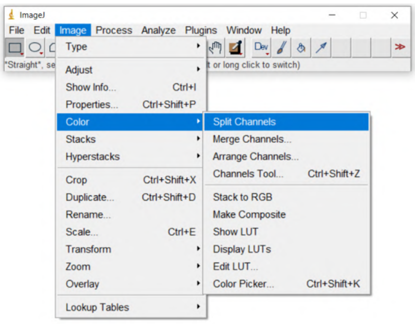

Figure 6. Process to split to the color channels.

Figure 7. Resulting split channels for the wood sample.

opens, select the rectangle tool from the toolbar, which is the leftmost option on the console. By default, the rectangle tool is already selected when you open *ImageJ*. The rectangle formed on the sample will be the area of analysis for *ImageJ*.

A rectangle was traced over the middle portion of the wood sample using the rectangle tool. This was recorded on the Recorder window with the coordinates of the rectangle corners, as depicted in figure 9.

To measure the color brightness of this particular area, press M on the keyboard. This will run the measure function on the Recorder. A new Results window will appear displaying the results of the rectangle area, as well as the mean, minimum and maximum brightness measurement inside the rectangle, like in figure 10.

To officially make the macro, click Create on the Recorder window. A new macro window will appear on the screen, as in figure 11. Save this macro with File > Save As, like in figure 12. The macro will be renamed to the chosen File name. The macro is officially made and you

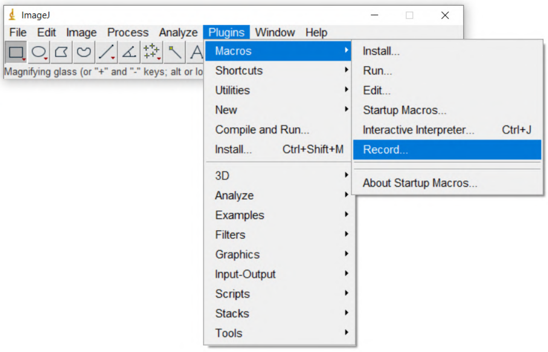

Figure 8. The process for making macros.

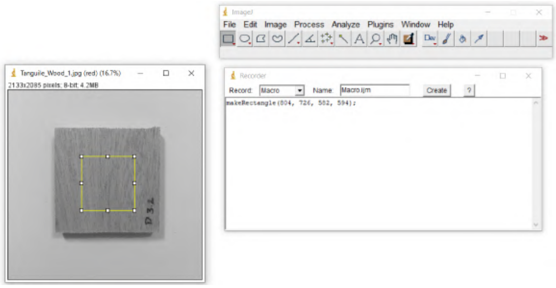

Figure 9. The mechanism for the rectangle measurement.

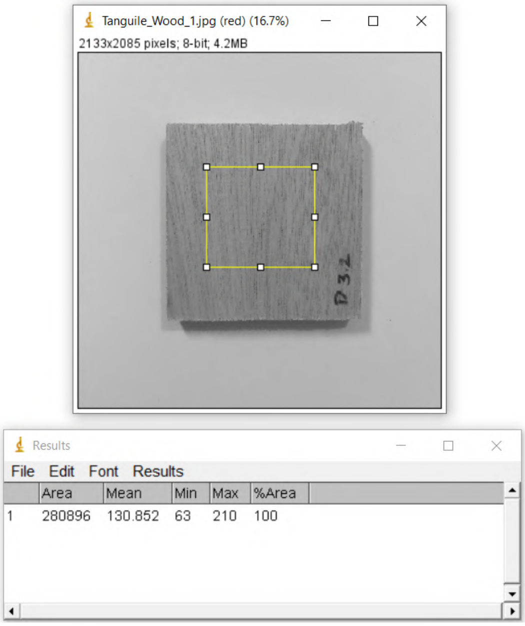

Figure 10. The color measurement for the image on *ImageJ*.

can close the Recorder window.

To recall the macro and subsequently get the brightness for the other color channels, go to Plugins > Macros > Run, and then select the saved macro, as in figure 13. The software will draw the rectangle in the same position according to the exact coordinates and get the brightness measurements in the same Results window. Once all measurements are taken from the samples, the data can be saved with File > Save As, or copied and pasted onto data processing software, like Microsoft Excel.

The measurements on *ImageJ* are done in the RGB scale. However, most data reported in the literature for wood photodegradation is done in the CIEL*a*b* system [14]. To convert the RGB measurements into CIEL*a*b*, we can use the Python *Colormath library* [20]. For this program, Spyder with Python 3.8 was used, although it is possible to do the conversion on other python integrated development environments (IDEs). On the console, import sRGBColor and

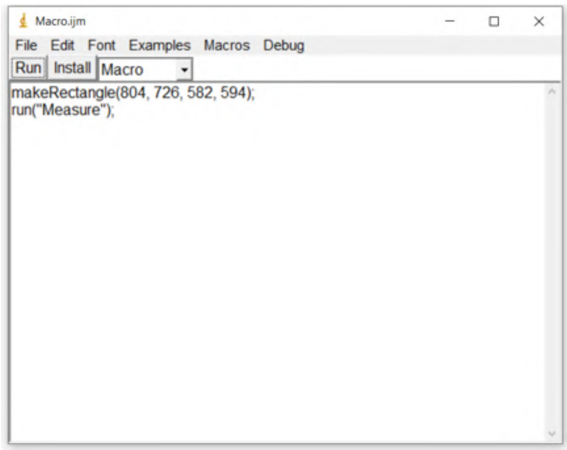

Figure 11. Recorder feature on *ImageJ*.

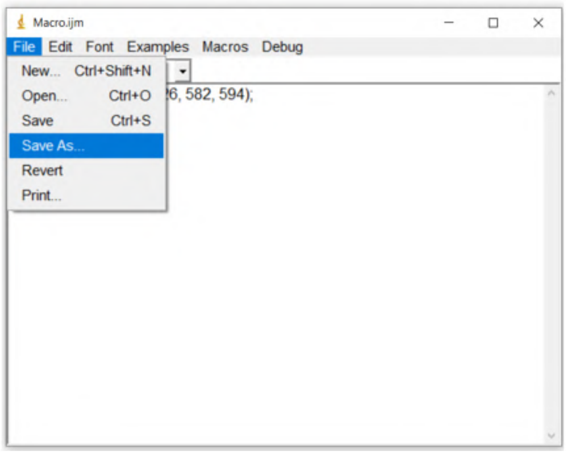

Figure 12. Saving the macro on *ImageJ*.

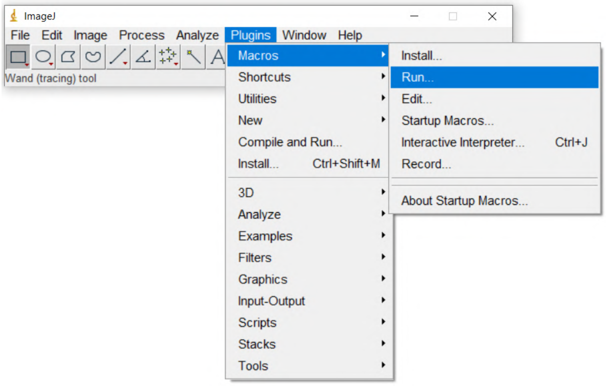

Figure 13. Running a macro on *ImageJ*.

LabColor from Color Objects and convert_color from Color Conversions. Insert your RGB color values inside the sRGBColor function. Do note that the conversion is done with the RGB values scaled from 0 to 1. To do this, simply divide the RGB values by 255.

Convert your RGB values to L*a*b* values with the convert_color function [20]. The parameters are the original color system, and the system you want to convert into. For the CIEL*a*b* system, there are two extra parameters concerning the observer and illuminant. For this conversion, the 10 degree observer was used, along with the D65 illuminant. The white point D65 is an estimation of the white color produced by mid-day sunlight [21]. These specifications are in line with reported literature on photodegradation of wood [22]. To get your converted values, simply use the print function. The values will be displayed on the console, like in figure 14.

3. Results and Discussion

By qualitative observation with the naked eye, it can be rather difficult to observe any obvious color changes like in figure 15 depending on the type of wood, which makes quantitative color analysis necessary.

```python
# -*- coding: utf-8 -*-
"""
Created on Thu Oct 28 14:44:44 2021

RGB to LAB color conversion using the colormath library
"""

#import colormath library
from colormath.color_objects import sRGBColor, LabColor
from colormath.color_conversions import convert_color

#set the RGB color values, scaled from 0 to 1 by dividing by 255
rgb = sRGBColor(127.076/255, 82.691/255, 45.832/255) #scaled from 0 to 1

#convert to LAB values with 10 degree observer and D65 Standard Illuminant
lab = convert_color(rgb, LabColor, observer ='10', target_illuminant='D65')

#print numbers as values
print(lab)
```

Figure 14. Color conversion using the Python *Colormath library.*

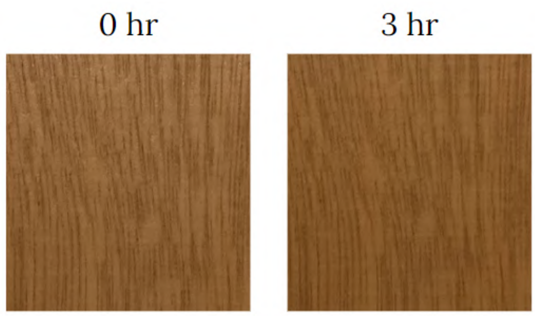

Figure 15. Tanguile wood before and after exposure to UV light.

Table 1 shows the mean RGB channel values similar to the one depicted in figure 10, and the corresponding CIEL*a*b* parameters obtained from the color conversion console in figure 14. As shown in table 1, Tanguile wood samples displayed a decrease in the lightness values, L*, regardless of the exposure time, meaning the samples got darker overall [23]. This is in contrast with the varying changes across the green-red axis, a* , which had samples that turned more red, while others became less red [7]. The results for the blue-yellow axis, b*, were slightly more consistent, displaying a decrease in the b* value for 1 and 2 hours of exposure and turned less yellow [24]. However, by the 3 hour exposure time, b* increased, which implies that the sample turned more yellow.

Using the converted CIEL*a*b* measurements in table 1, it is possible to get the overall color change, ΔE, given by the square of the differences between two values as indicated in equation (1). This is in accordance to the ISO 11664-6 (2014) standard, which takes the color change between exposed and unexposed samples for all CIEL*a*b* measurements [25]. The parameters L_1^*, a_1^*, and b_1^* refer to the CIEL*a*b* measurements before artificial weathering while L_2^*, a_2^*, and b_2^* refer to the measurements after artificial weathering. Using equation (1) yielded a value of a maximum of 4.29 after three hours displayed in table 2, which, according to the literature, represents appreciable color change [25]. This is further represented by figure 16, which appears to show a linear increase in the overall color change after three hours. Even at three hours of UV exposure, UV light already has an effect on wood. For future experiments it would be interesting to observe the effects on wood beyond three hours to have a greater understanding on the degree of photodegradation on the wood samples.

Table 1. Mean RGB channel values and converted CIEL*a*b* measurements for samples of Tanguile wood exposed to UV for 1, 2, and 3 hours.

Time		R	G	B	L*	a*	b*
1 hr	Before	130.41	87.207	45.605	40.94	13.53	30.96
	After	125.469	83.48	42.292	39.30	13.23	30.71
2 hr	Before	138.102	94.978	50.764	44.00	12.86	31.93
	After	132.129	88.932	47.635	41.64	13.45	30.70
3 hr	Before	141.789	97.671	52.58	45.18	13.10	32.44
	After	131.104	87.05	42.283	40.95	13.71	32.80

$$\Delta E = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)} \tag{1}$$

Table 2. Calculated values for ΔL*, Δa*, Δb*, and ΔE at different exposure times for Tanguile wood samples.

Time	ΔL*	Δa*	Δb*	ΔE
1 hr	−1.64	−0.30	−0.25	1.69
2 hr	−2.36	0.59	−1.23	2.73
3 hr	−4.23	0.61	0.36	4.29

Although chemical analysis is beyond the scope of this paper, it is noteworthy that the color analysis measurements were supported by the decrease in the absorbance (A) ratio at A1340/A1320 during ATR-FTIR spectroscopy in table 3, where A1340/A1320 denotes the absorbance at 1340 cm^{-1} wavenumber divided by the absorbance at 1320 cm^{-1}. $(A1340/A1320)_0$ denotes the ratio before artificial weathering, while $(A1340/A1320)_t$ denotes the ratio for both wavenumbers after artificial weathering. Colom, Carrillo, Nogués, and Garriga used the absorbance (A) ratio between 1335 cm^{-1} and 1316 cm^{-1}, but for this study the closest set of data for the Tanguile wood were at the 1340 cm^{-1} and 1320 cm^{-1} [6]. The decrease in ratio infers that there is increased cellulose I content of the wood that evolves and crystallizes [6]. This then supports the idea that reactions are taking place within the wood samples during photodegradation.

4. Summary and Conclusion

In the absence of a spectrophotometer, the use of image processing programs in color analysis can be a reliable alternative to probe wood photodegradation. As shown in this study, color analysis was successfully conducted using *ImageJ* and Colormath library software for a simple, work-from-home setup. Regardless of the exposure time, the wood samples become darker as indicated by the negative value in the change in lightness L*. Our data show a linear increase in the overall color change ΔE as a function of UV exposure time from one to three hours. After three hours of exposure, the maximum ΔE value of 4.29 indicates appreciable color change, according to the criteria from literature. This suggests photodegradation in the wood samples and can be supported in later characterization under ATR-FTIR spectroscopy.

Table 3. Absorbance (A) ratios for 1340 cm^{-1} and 1320 cm^{-1} wavenumbers of the Tanguile wood samples exposed in UV for three hours.

Ratio	Value
$(A1340/A1320)_0$	0.978
$(A1340/A1320)_t$	0.567

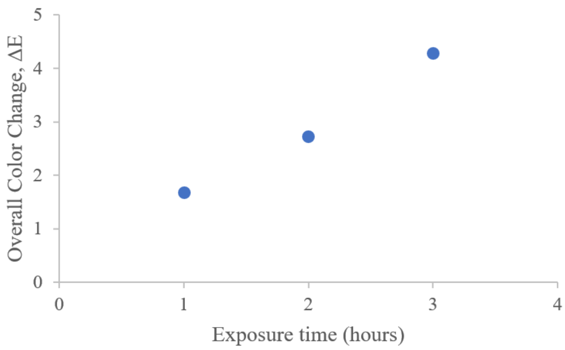

Figure 16. Overall color change as a function of exposure time for Tanguile samples during UV photodegradation.

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Mathematical model of the base unit of the biotechnical system as a type of edge devices

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Mathematical model of the base unit of the biotechnical system as a type of edge devices

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Abstract. The rapid development of computer biometrics over the past 2-3 decades is largely due to the development and widespread introduction into clinical practice of new methods of studying the human body health, including pulse methods. It is possible to judge changes in hemodynamic characteristics, heart rate and blood flow rate in the studied part of the body based on the parameters of the pulse wave signal. At the same time, the physical processes of formation of the pulse wave shape have not been fully studied, although the number of biophysical models of blood circulation is quite significant. The development of such a model will allow to effectively apply modern developments in digital signal processing to the pulse wave and increase its diagnostic value. Qualitative model of pulse signal can be entrusted to the development of the base unit of the biotechnical system as a type of edge devices. The work is devoted to the improvement of methods of rapid diagnosis of the cardiovascular system based on the analysis of model pulsegrams. An adequate mathematical model of the pulse wave, which corresponds to real pulse signals in different states of the human body and contains mathematical relationships between the main parameters of pulsegrams, has been refined. The algorithm of express diagnostics with the established criteria of the analysis of pulsograms is offered.

1. Introduction

The rapid development of computer biometrics over the past 2-3 decades is largely due to the development and widespread introduction into clinical practice of new methods of studying the human body health, including pulse methods. It is possible to judge changes in hemodynamic characteristics, heart rate and blood flow rate in the studied part of the body based on the parameters of the pulse wave signal. At the same time, the physical processes of formation of the pulse wave shape have not been fully studied, although the number of biophysical models of blood circulation is quite significant. However, none of them meets all the requirements for models of the pulse signal in terms of rapid and pulse diagnostics, namely:

- match with the real signal in all areas of blood circulation;
- not only the form reproduction, but also the explanation of the pulse wave genesis;
- description of the circulatory system activity in the diastolic phase;
- presence of mathematical equations that coordinate the basic parameters of blood flow;
- relative simplicity of interpretation with sufficient information value.

The development of such a model will allow to effectively apply modern developments in digital signal processing to the pulse wave and increase its diagnostic value. Qualitative model of pulse signal can be entrusted to the development of the base unit of the biotechnical system as a type of edge devices (figure 1).

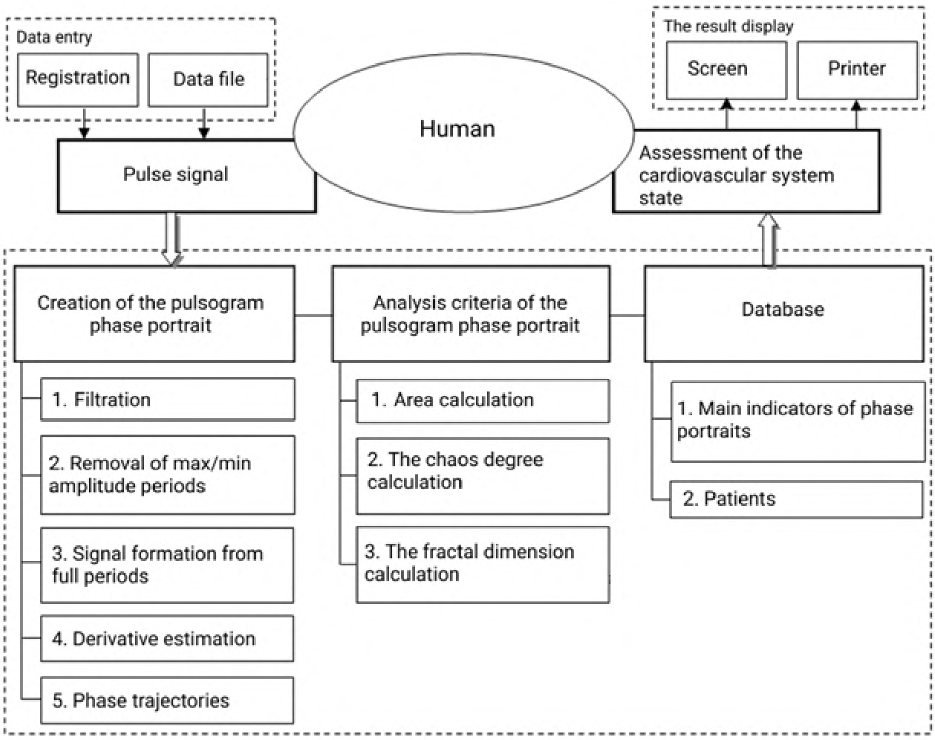

Figure 1. Block diagram of the automated biotechnical system of pulsegram analysis.

2. Theoretical background

Edge device is a peripheral device capable of forwarding packets between traditional interfaces (e.g. Ethernet, Token Ring, etc.) and ATM based on channel or network layer information. However, it is not involved in any routing protocol on the network [1].

According to joint study of Ezhilmathi Krishnasamy, Sebastien Varrette, Michael Mucciardi, a large amount of patient's data can be analyzed on the periphery. Next it needs to be transformed. Only after that the relevant data can be sent to the cloud. According to the scientists, "peripheral medical imaging eliminates latency and dependence on cloud computing resources, as well as reduces the patient's digital footprint by limiting the number of systems that have access to data" [2].

Another group of authors describe how Edge Computing is used in the healthcare system (figure 2) [3]. Scientists claim that edge computing make the modern health care system more critical and sensitive by reducing the time spent on data transmission compared to the autonomous cloud system [3].

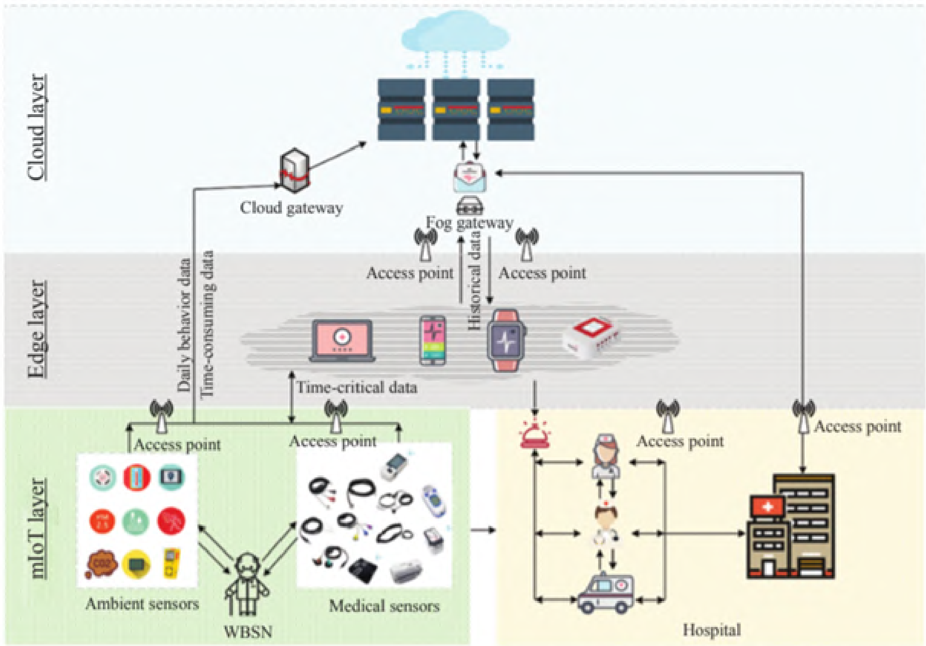

Figure 2. Edge Computing in Healthcare [3].

According to source [4], the eLifeCare platform uses AI on the Edge level (figure 3). Scientists say that the platform acts as an alert system using early warning indicators (some forms of edge devices) [4].

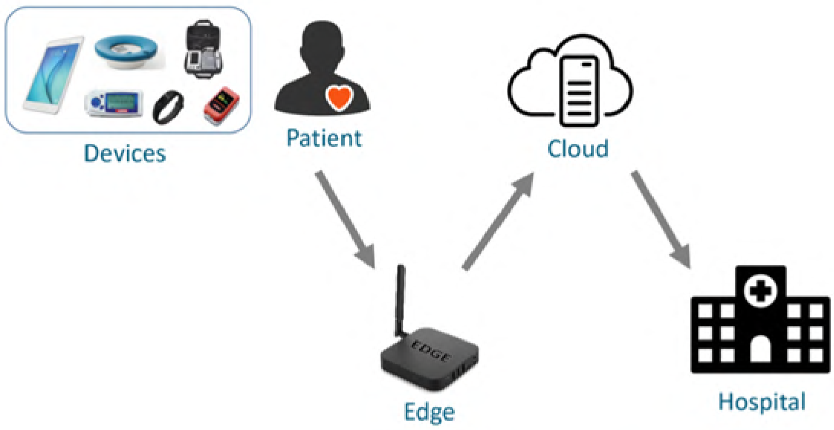

Figure 3. Healthcare Scenario in AAL [4].

Another group of researchers consider the architecture of fog-based applications [5]. They note that such an architecture consists of three layers: Thing Layer, Fog Layer and Cloud Layer. In particular, the Thing Layer level includes end-user devices (edge devices) (figure 4). Those are Arduino motherboards, IoT devices, sensors, body data collection tools (e.g. blood pressure, heart rate, glucose) and so on [5].

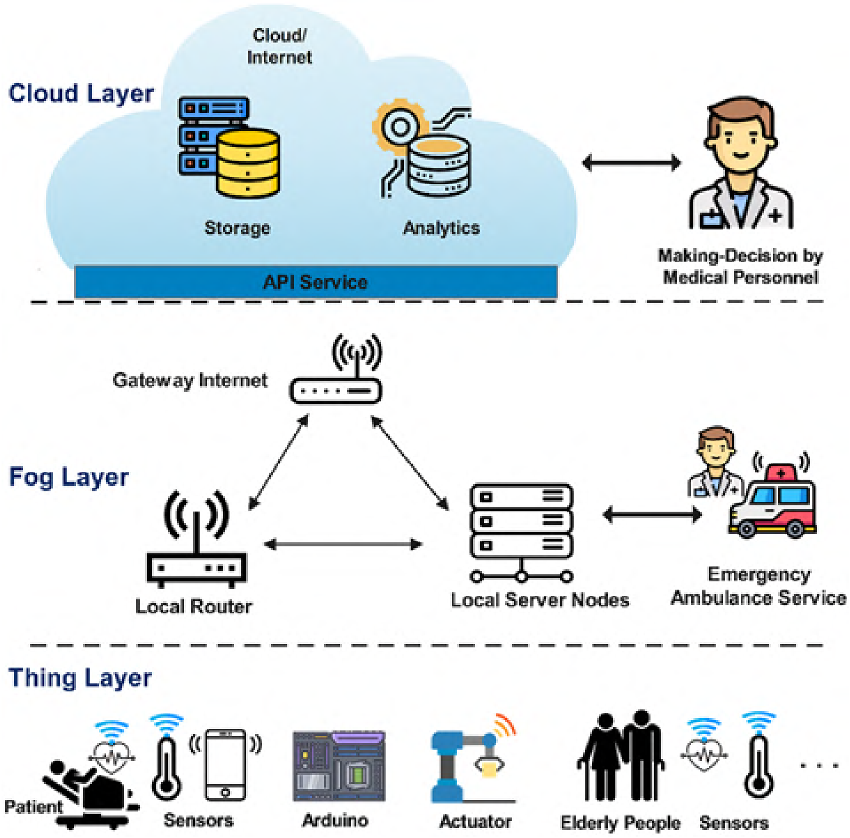

Figure 4. Fog-based application architecture [5].

The authors of [6] suggest architecture for edge devices for diagnostics of students' physical condition. The biotechnical system can then be built based on their research.

Therefore, the aim of this article is to develop a mathematical model of pulse wave, which will correspond to the real pulse signals for certain types of pulsations in the circulatory system, contain mathematical relationships between basic parameters of pulsegrams and will be the basis of biotechnical system to improve rapid diagnostics of cardiovascular system.

3. Research methodology

In the methodological aspect, the study of such complex systems as physiological is carried out on adequate mathematical models using modern computer technology. Data analysis includes:

- mathematical description, modeling and parameterization of data;
- data classification by diagnostic categories in order to further automate the conclusion;
- graphic or other visual presentation of the results for the diagnostician.

In the first stage, the selected and/or improved model is analyzed and calculated on a PC (which is a model computational experiment). It should be kept in mind that modeling is a process of studying a phenomenon with the help of mathematical equations. The model is just a simplified description of real phenomena and processes. Therefore, the results obtained by computer simulation need further confirmation (for example, by conducting a clinical experiment).

The second stage is the calculation of the object's characteristics, the definition of diagnostic criteria and the creation of an identification box (expert system) in order to automate the conclusion in further clinical trials.

At the last stage of computer analysis, the conclusion is performed and result is displayed in visual form (monitor screen) and/or graphical representation for the diagnostician.

The algorithm for automated inference about the state of a physiological object by creating a classification base (identification box) with the use of model data is shown in figure 5.

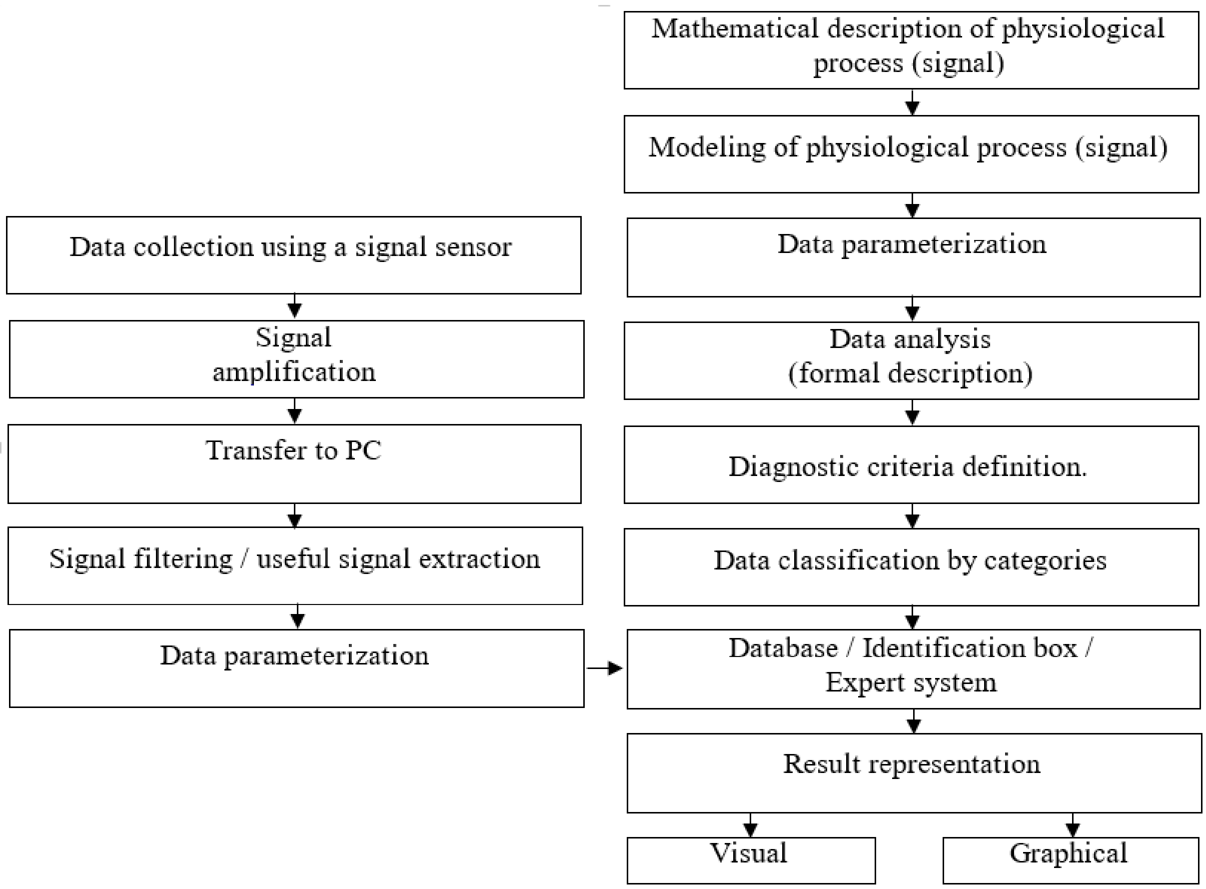

Figure 5. Algorithm for conducting research and automatic inference about the state of a physiological object using model data.

Each of the listed stages of data processing and processes analysis in a certain period of time quickly improves, moving to a higher quality level almost abruptly. For example, acquainting a doctor with a diagnosis (conclusion about the state of the biological system), set by the computer automatically, helps to increase the accuracy of the final diagnostic conclusion [7].

4. Results

Based on the analysis of existing biophysical models of blood circulation [8–14], it follows that none of the existing models reflects all elements of the pulse wave accurately enough. Therefore, they cannot be used in developing new methods for analyzing pulse signals in particular and the cardiovascular system in general. However, the harmonious model of blood circulation and the model of active diastole can be considered as those that accurately reflect the genesis of pulse waves. They are quite simple and are partially confirmed by practical results [13].

Based on these two models, a mathematical model of blood circulation was developed in [13, 14]. It was called harmonic three-phase. According to this model, the activity of the circulatory system is considered to be three-phase, i.e. the pulse signal is formed by three components: systolic, dichroic and presystolic [13].

The model is a one-dimensional signal, the position of the extremes and characteristic points of which corresponds to a human pulse wave without pathologies of the cardiovascular system. The duration is chosen based on several heartbeats. In terms of data set, this curve is an array of 600 discrete points, which corresponds to a signal with a sampling frequency of 100 Hz (the value of the pressure in the model is calculated at intervals of 0.01 sec.)

The model analysis procedure gives an idea of the effectiveness and feasibility of applying appropriate software and algorithms to the real signal. A fragment of the model is graphically shown in figure 6.

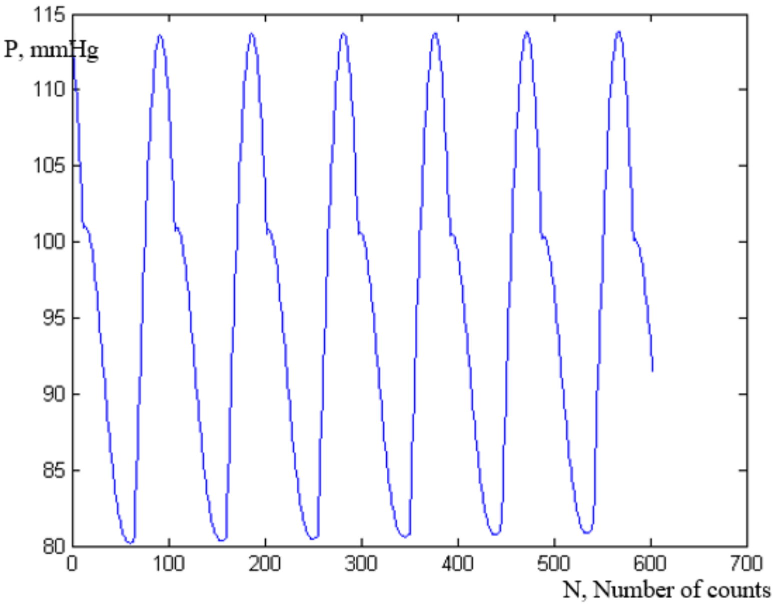

Figure 6. A fragment of the model signal.

Assume that the real and mathematically described pulse signals are identical [7]. That is, the pulse wave mathematical equation can be developed for the selected 6 types of pulse presented in the classification system based on the variability of the pulsegram characteristics during the diagnostic procedure [7], with the definition of the corresponding dysfunctions of the cardiovascular system.

General view of the mathematical equation of the pulse wave

$$p = p_a + p_0 \cdot \cos\omega(t - \frac{l}{v}) + p_0' \cdot |\sin\omega'(t - \frac{l}{v} + \varphi')| + 1.5 \cdot p_0'' \cdot |\sin\omega''(t - \frac{l}{v} + \varphi'')| \quad (1)$$

or, considering $\omega'' = \omega' = \frac{\omega}{2} = 3.30$ and $p_0'' \approx p_0'$,

$$p = p_a + p_0 \cdot \cos\omega(t - \frac{l}{v}) + 1.5 \cdot p_0 \cdot |\sin\frac{\omega}{2}(t - \frac{l}{v} + \varphi')| + 1.5 \cdot p_0 \cdot |\sin\frac{\omega}{2}(t - \frac{l}{v} + \varphi'')| \quad (2)$$

Taking into account the nominal parameters of blood flow for the category of people with the same type of anthropometric and physiological parameters, without obvious dysfunctions of the heart, the mathematical equation for the pulse signal of “even pulse”

$$\begin{aligned} p_{even} = 50 + 18.75 \cdot \cos 6.61(t - \frac{0.06}{6.8}) + 28.13 \cdot |\sin 3.30(t - \frac{0.06}{6.8} + 0.12)| + \\ +28.13 \cdot |\sin 3.30(t - \frac{0.06}{6.8} - 0.30)| = 50 + 18.75 \cdot \cos 6.61(t - \frac{0.06}{6.8}) + \\ +28.13 \cdot |\sin 3.30(t + 0.11)| + 28.13 \cdot |\sin 3.30(t + 0.29)| \end{aligned} \tag{3}$$

According to the equation, computer simulation of the signal "even pulse" was conducted (figure 7).

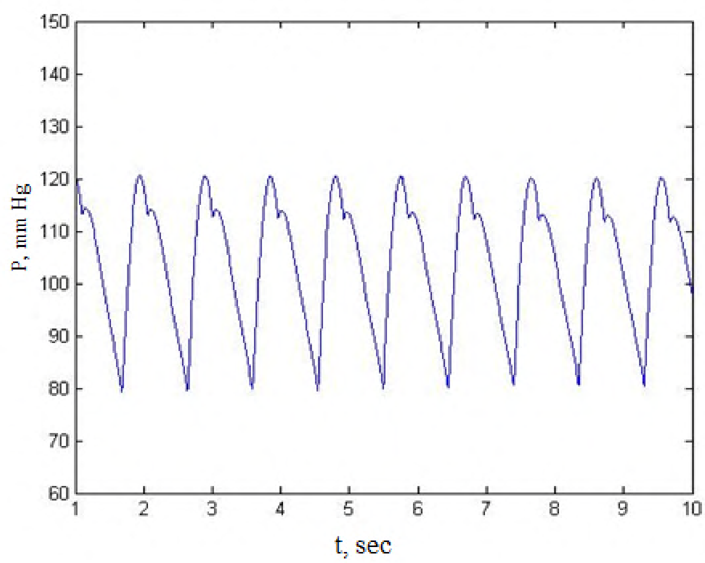

Figure 7. Model signal of "even" pulse.

Equation for pulse signal type "uneven pulse":

$$\begin{aligned} p_{uneven} = 50 + 18.75 \cdot \cos 6.61(t - \frac{0.06}{6.8}) + 28.13 \cdot |\sin 3.30(t - \frac{0.06}{6.8} + 0.15)| + \\ +28.13 \cdot |\sin 3.30(t - \frac{0.06}{6.8} + 0.22)| = 50...55 + 18.75 \cdot \cos 6.61(t - 0.0088) + \\ +28.13 \cdot |\sin 3.30(t + 0.14)| + 28.13 \cdot |\sin 3.30(t + 0.21)| \end{aligned} \tag{4}$$

By changing the hemodynamic parameters included in the equation of the pulse wave, a graph of the "uneven" type of pulse was obtained by computer simulation (figure 8).

Equation for pulse signal type "high pulse"

$$\begin{aligned} p_{high} = 60 + 18.75 \cdot \cos 6.61(t - \frac{0.06}{6.8}) + 28.13 \cdot |\sin 3.30(t - \frac{0.06}{6.8} + 0.09)| + \\ +28.13 \cdot |\sin 3.30(t - \frac{0.06}{6.8} + 0.32)| = 60 + 22.5 \cdot \cos 6.61(t - 0.0088) + \\ +34.6 \cdot |\sin 3.30(t + 0.08)| + 34.6 \cdot |\sin 3.30(t + 0.31)| \end{aligned} \tag{5}$$

The graphic result of computer simulation of "high" pulse is shown below (figure 9).

The equation for the type of pulse signal "low pulse", shown in figure 10.

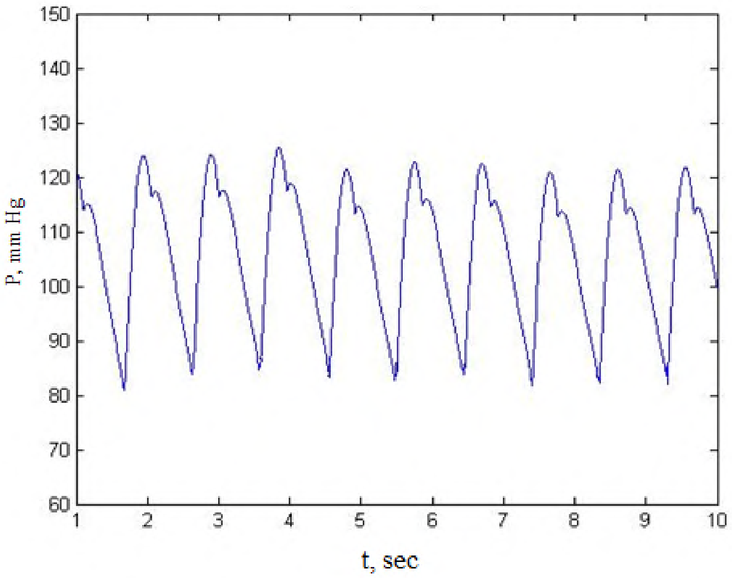

Figure 8. Model signal of “uneven” pulse.

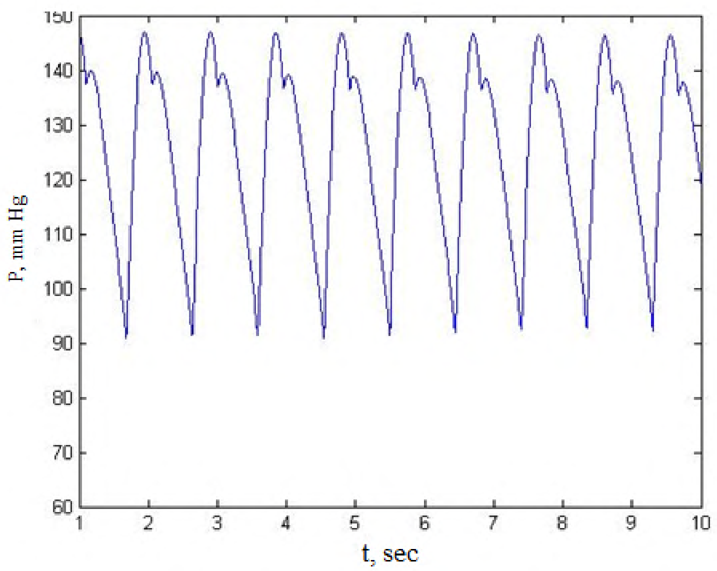

Figure 9. Model signal of “high” pulse.

$$p_{low} = 45 + 9.4 \cdot \cos 6.61(t - \frac{0.06}{6.8}) + 33.8 \cdot |\sin 3.30(t - \frac{0.06}{6.8} + 0.9)| + \\ +33.8 \cdot |\sin 3.30(t - \frac{0.06}{6.8} + 0.2)| = 45 + 9.4 \cdot \cos 6.61(t - 0.0088) + \\ +33.8 \cdot |\sin 3.30(t + 0.89)| + 33.8 \cdot |\sin 3.30(t + 0.19)| \tag{6}$$

The type of pulse “fast” is described by the equation:

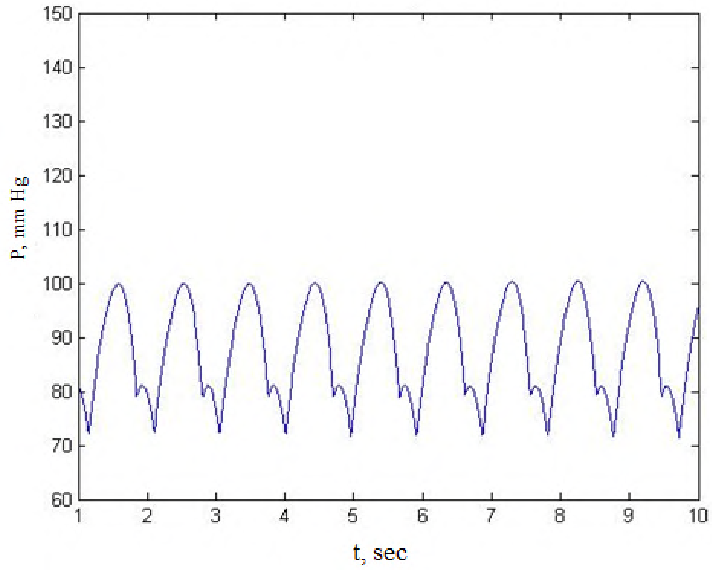

Figure 10. Model signal of "low" pulse.

$$p_{fast} = 75 + 45.13 \cdot \cos 6.61(t - \frac{0.06}{6.8}) + 28.13 \cdot |\sin 3.30(t - \frac{0.06}{6.8} + 0.135)| + \\ +33.8 \cdot |\sin 3.30(t - \frac{0.06}{6.8} + 0.06)| = 75 + 43.13 \cdot \cos 6.61(t - 0.0088) + \\ +33.8 \cdot |\sin 3.30(t + 0.126)| + 33.8 \cdot |\sin 3.30(t + 0.05)| \tag{7}$$

The graphic result of computer simulation of "fast" pulse is shown in the figure 11.

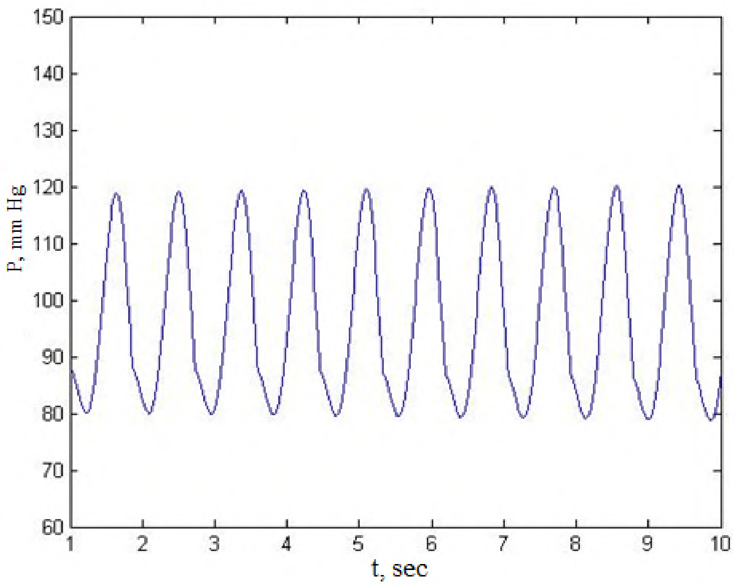

Figure 11. Model signal of "fast" pulse.

By changing the hemodynamic parameters included in the equation of the pulse wave, the equation and the graph of the "slow" type of pulsations are obtained (figure 12).

$$
\begin{aligned}
p_{slow} = 80 + 20.63 \cdot \cos 6.61(t - \frac{0.06}{6.8}) + 16.88 \cdot |\sin 3.30(t - \frac{0.06}{6.8} + 0.075)| + \\
+16.88 \cdot |\sin 3.30(t - \frac{0.06}{6.8} + 0.055)| = 80 + 20.63 \cdot \cos 6.61(t - 0.0088) + \\
+16.88 \cdot |\sin 3.30(t + 0.066)| + 16.88 \cdot |\sin 3.30(t + 0.046)|
\end{aligned} \tag{8}
$$

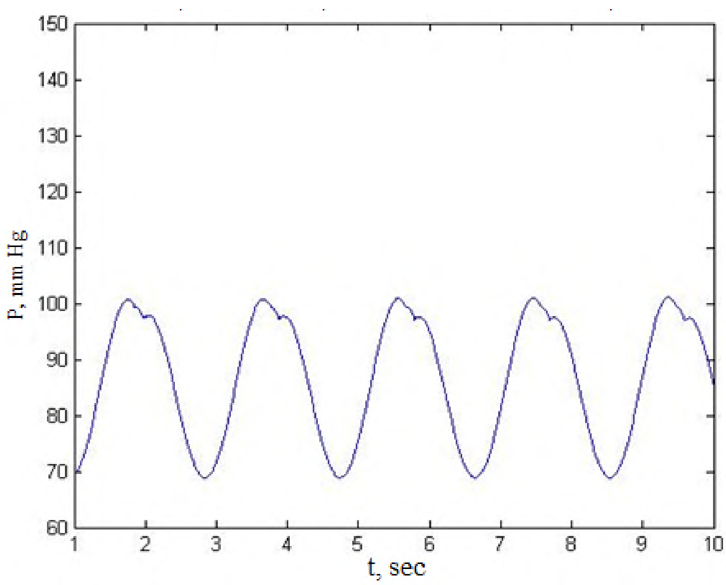

Figure 12. Model signal of "slow" pulse.

The obtained mathematical equations of signals for six types of pulse are presented in the phase plane. The numerical indicators of phase portraits of pulsegrams are investigated (PPP) in order to determine the criteria for rapid diagnosis.

For the purpose of carrying out express diagnostics on pulsegrams it is necessary to receive indicators on which the conclusion will be automatically received. It is expedient to plow with the phase plane method substantiated in [7].

According to [7], phase portrait can be formed by putting on one axis the signal itself $p = x(t)$, and on the other one - its derivative $x(t) = p(t)$ (figure 13).

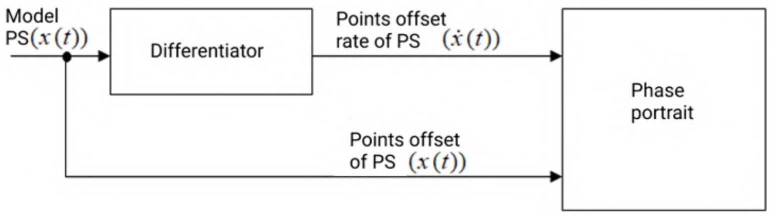

Figure 13. Algorithm for forming a phase portrait of a model pulse signal.

Mathematical equations ((3) – (8)) are differentiated and the corresponding ones are obtained $x(t) = p(t)$ for each type of pulse. The visualization of the phase trajectory of the pulsegram

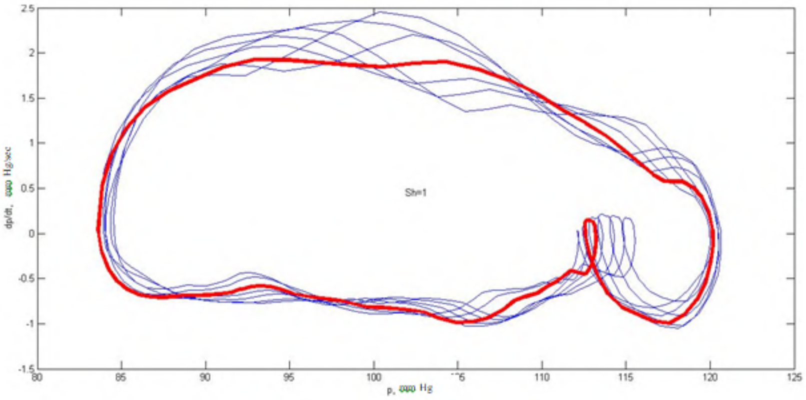

Figure 14. Phase portrait of “even” pulse.

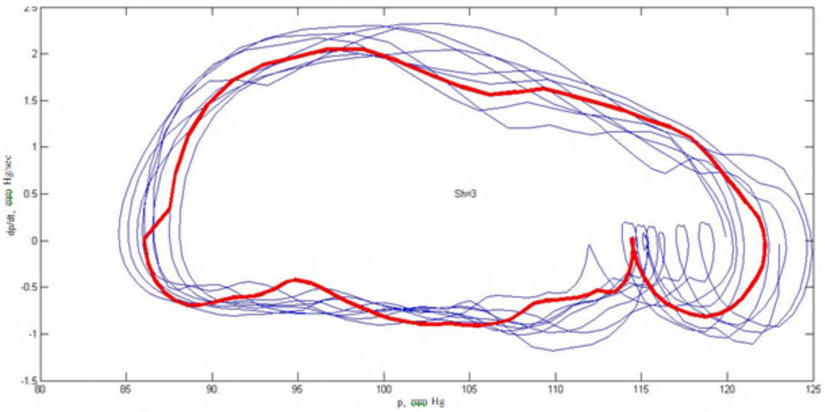

Figure 15. Phase portrait of “uneven” pulse.

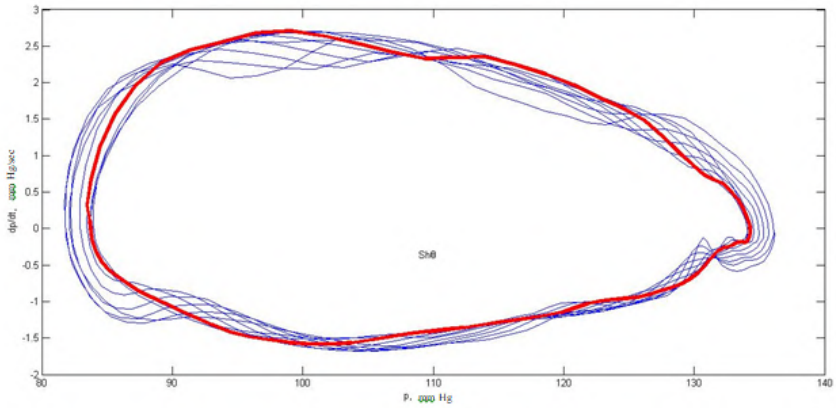

Figure 16. Phase portrait of “high” pulse.

periods in the coordinates $p-\frac{dp}{dt}$, corresponding to the coordinates $x-y$, is presented in figure 14, figure 15, figure 16, figure 17, figure 18, figure 19.

To quantify the trajectories in the phase plane in [7] the following indicators are considered:

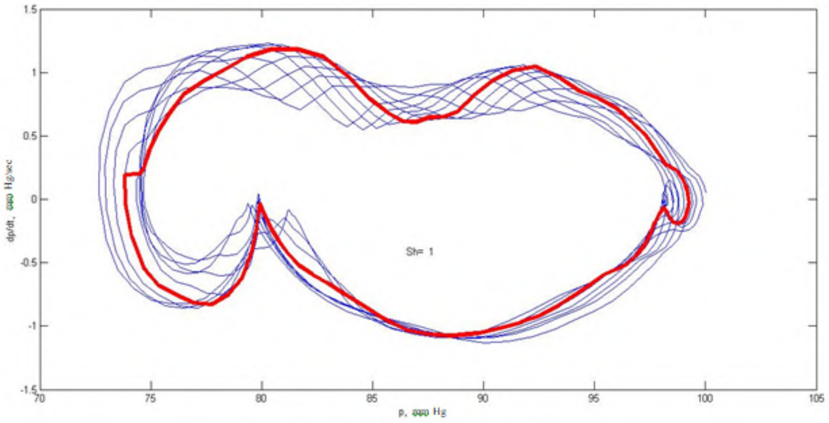

Figure 17. Phase portrait of "low" pulse.

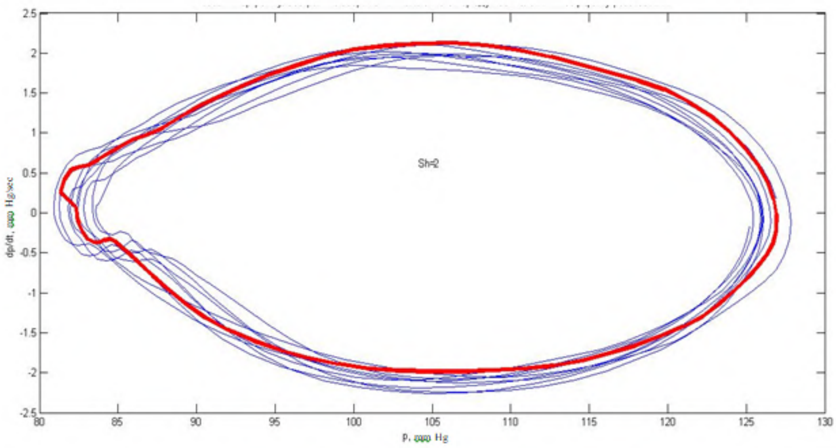

Figure 18. Phase portrait of "fast" pulse.

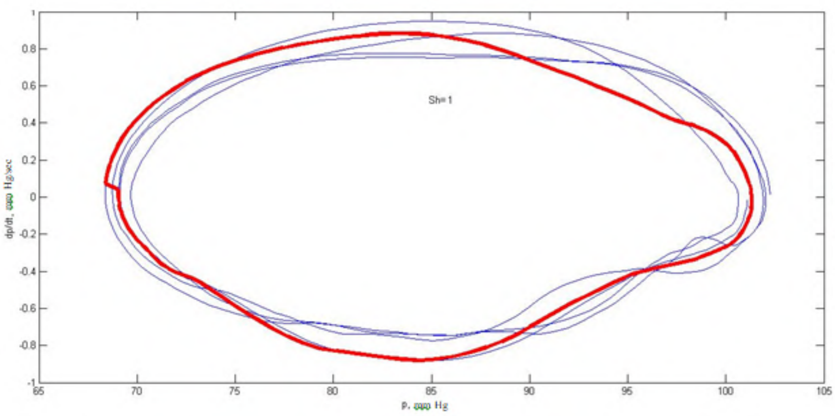

Figure 19. Phase portrait of "slow" pulse.

- area of the phase portrait S – the number of occupied cells in the plane;
- degree of chaos Sh;

- fractal dimension (maximum length (diameter) of the phase portrait) D.

The literature sources show the range of changes in the pulse wave, which allowed to obtain sets of curves according to equations (3) - (8) for each type of pulse. Pulse signals have been presented in the phase plane and their phase portraits have been obtained, according to which the values of PPP characteristics have been calculated (Tables 1 and 2).

Table 1. Numerical values of PPP indicators.

	Pulse Type								
	"even"			"uneven"			"slow"		
№	Sh	S	D	Sh	S	D	Sh	S	D
1	0,6002	666290	36,5302	2,5924	701640	36,1376	1,0931	711620	32,9156
2	0,5901	669990	36,9108	2,5601	700090	35,0056	1,0865	712900	31,9527
3	0,5952	670000	36,5934	2,5333	700700	35,0000	1,0876	713660	32,0095
4	0,6302	668080	38,7224	2,5599	698730	35,0006	1,0565	714590	34,7889
5	0,6299	662390	38,0076	2,5436	693070	35,1551	1,0467	713050	33,4562
6	0,6234	660720	39,0867	2,5502	697540	35,1456	1,0564	719800	33,0845
7	0,6301	659890	37,00765	2,5101	698760	35,1305	1,0922	718540	33,789
8	0,6345	661730	37,6908	2,3678	690740	35,1809	1,0928	722300	34,7655
9	0,6149	663420	37,2829	2,3658	689020	35,6006	1,0205	720560	33,0098
10	0,6178	663980	39,11762	2,2201	685140	35,5972	1,0198	726770	34,7733

Table 2. Numerical values of PPP indicators.

	Pulse Type								
	"fast"			"high"			"low"		
№	Sh	S	D	Sh	S	D	Sh	S	D
1	1,5937	657740	45,5758	0,4924	710170	50,8056	0,879	783990	25,4254
2	1,5003	639070	45,0995	0,506	709060	50,72135	0,9201	784060	24,43862
3	1,5504	649080	47,856	0,5605	706800	51,275	0,9056	783400	23,7623
4	1,6980	650720	47,9008	0,5567	709570	54,8769	0,8069	783650	22,9876
5	1,4280	636070	46,0405	0,5501	705010	54,623	0,8878	784520	22,1687
6	1,4408	641890	46,0667	0,5598	705250	51,0432	0,8974	780040	21,7986
7	1,6202	643950	48,0005	0,5344	705440	53,7634	0,8834	775400	25,1278
8	1,4490	651380	47,9623	0,5201	706800	54,978	0,8001	776920	25,786
9	1,4208	657060	47,9405	0,5143	707020	54,0065	0,8567	776050	20,987
10	1,4187	634990	48,0018	0,5104	705920	51,68788	0,8444	774700	19,28445

Using the methods of mathematical statistics, the range of values A_{k_j}, where j_k – pulse type with k-th PPP indicator, $j = \overline{1,n}$, $n = 6$, $k = \overline{1,h}$, $h = 3$, are defined as the maximum value A_{max} and minimum value A_{min} within each pulse type

$$A_{k_j} = A_{max} ... A_{min} \tag{9}$$

The results of calculation are shown in tables 3 and 4.

Table 3. Intervals $A_{min}...A_{max}$ of the analysis criteria of pulsegrams.

	Pulse Type					
Features of PPP	"even"	"uneven"	"slow"	"fast"	"high"	"low"
Fractal dimension, D	36,5302 … 39,1176	35,000 … 36,1376	31,9527 … 34,7889	45,0995 … 48,0018	50,7214 … 54,9780	19,2844 … 25,7860
Degree of chaos, Sh	0,5901 … 0,6345	2,2201 … 2,5924	1,0198 … 1,0931	1,4187 … 1,6980	0,4924 … 0,5605	0,8001 … 0,9201
Area, S	659890… … 670000	685140… … 701640	711620… … 726770	634990… … 657740	705010… … 710170	774700… … 784520

Table 4. Confidence intervals $A_{min}...A_{max}$ of the analysis criteria of pulsegrams.

	Pulse Type					
Features of PPP	"even"	"uneven"	"slow"	"fast"	"high"	"low"
Fractal dimension, D	36,982 … 38,408	35,0305 … 35,5603	32,6885 … 34,2205	46,1923 … 47,8966	51,4784 … 54,0777	21,6591 … 24,6942
Degree of chaos, Sh	0,6051 … 0,6282	2,3939 … 2,5667	1,0652 … 1,0442	1,4414 … 1,5826	0,5125 … 0,5484	0,8392 … 0,8971
Area, S	661979,9 … 667318,1	691490,1 … 699595,9	713815,7 … 720942,3	640308,4 … 652081,6	705765,9 … 708442,15	777339,8 … 783206,2

That is, the pulse type will be determined as

$$y_j = \begin{cases} A_{Sh}, & A_{minSh} \leq A_{Sh} \leq A_{maxSh} \\ A_S, & A_{minS} \leq A_S \leq A_{maxS} \\ A_D, & A_{minD} \leq A_D \leq A_{maxD} \end{cases} \tag{10}$$

where y_j– inference y of a system regarding the pulse type j, $j = \overline{1, n}$, $n = 6$.

Then, the block diagram of the algorithm for analysis of pulsegrams with automated output can be depicted in figure 20.

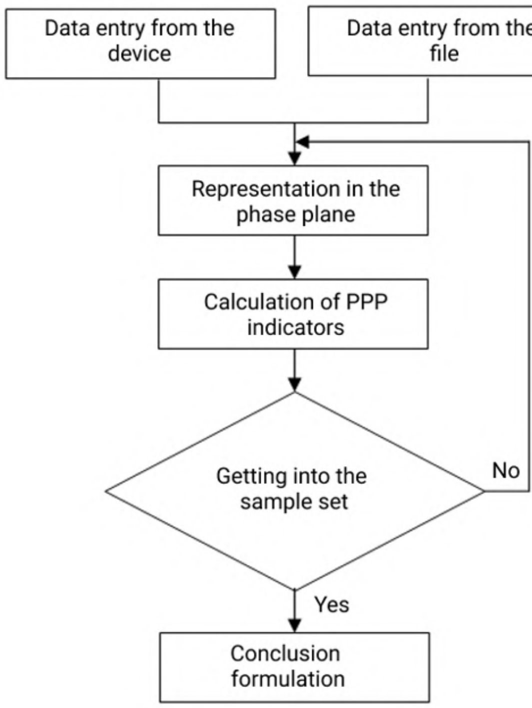

Figure 20. Algorithm for analysis of pulsograms with automated output.

5. Conclusions

When the researching the pulse signal, it is often necessary to calculate a large number of concomitant parameters that can provide information about the state of the cardiovascular system and the body as a whole. To calculate these parameters, it is necessary to have mathematical and physical relationships between specific indicators of the circulatory system. Substantiation of such relationships and dependencies is contained in biophysical models of blood circulation.

In this study, the feasibility of using a refined harmonic model of the pulse wave is substantiated, which is entrusted to the study of the possibility of rapid diagnosis of the cardiovascular system.

Based on the study, six functional sets are formed. Each of them contains an array of values from the analysis criteria - numerical characteristics of phase portraits of pulsegrams. These characteristics correspond to a particular pulse type, which will help to detect various pulsegrams, as well as diagnose cardiovascular system for lack of dysfunction.

The future biotechnical system that will be developed on the basis of this model of pulsograms will be a type of edge devices. This system will promote carrying out express organism diagnostics on pulse signals, and also will transfer results to the server of the remote diagnostic center.

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Study of ergonomic criteria for evaluating the software user interface

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Study of ergonomic criteria for evaluating the software user interface

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Abstract. This article summarizes research on the development and evaluation of a set of software usability measurements. Today they are called "ergonomic criteria". The authors summarize the research work carried out on the development and evaluation of a set of software usability measurements. The paper contains a description of each such criterion. All of them together provide a quality user interface. The authors highlighted the significant advantages of a well-designed and well-thought-out interface. The paper also contains an analysis of each of these criteria. The authors of the article discuss ergonomic problems of software development. As a result, some characteristics of the software are identified. They reduce the ergonomics of the user interface. The paper also discusses ergonomic issues and the things developers need to get rid of to make the app enjoyable. The success of solving this problem in software development largely depends on how functional, clear and user-friendly the interface is. The authors give some examples of bad user interfaces. They are accompanied by an explanation of the problems and solutions to these shortcomings. The systems, designed with practicality in mind, are ergonomic and work exactly as users expect, allowing users to focus on their own tasks rather than the specifics of interacting with the system.

1. Introduction

In the 21st century, in the age of digital transformation and automation of human activity, no one can do without any technical device. This allows you to expand or supplement natural capabilities such as complex computing, transmitting and receiving information, improving accuracy, moving in space, making decisions, and more.

The **aim** of this work is to identify the main set of measurements of ease of use, commonly known as "ergonomic criteria" based on a review of already written research papers. The research concerns the process and results of one branch of international standardization of human-system interaction. The article discusses the points where the results of standardization could be more successful.

Software developers solve many problems when designing a user interface (UI). As a result, users can use information systems efficiently and economically. Typically, developers consider the features of the software separately from its user interface. But some researchers believe that the user interface is a complement to system functions. But users do not differentiate between functionality and software interface. For UI this is the same program. For them, if the software interface is good, then the program itself is good and convenient. This means that this understanding of UI is too limited. In fact, the user interface contains all aspects of design that affect user-system interaction.

Innovations in technology and automation in control systems have increased the need to improve the user interface and all processes for its creation [1]. The benefits of Internet technology create a unique opportunity to quickly and efficiently provide employees with data and access to it. There have long been technologies that can significantly improve the UI. However, they alone do not produce ergonomic interfaces.

For example, the graphical user interface itself is no more ergonomic than the text interface. Experience has shown that it may be less useful if designed incorrectly [2].

Because the user considers the interface as a key factor in the functionality of the program, a poorly designed interface severely limits the functionality of the system as a whole [3]. Companies that do not seek to develop ergonomic UI for their products and get all the benefits provided by modern technology, weaken their competitive position. Timely and professional development of the interface leads to increased software efficiency [4]. And this reduces the duration of user training, reduces the cost of redesigning the system after its implementation, promotes the fullest use of the functionality embedded in the software, etc.

Software designed with practicality in mind is ergonomic and works exactly as users expect. As a result, users focus on their own tasks rather than the specifics of interacting with the software. Ergonomic software products are easier to learn, they are more effective, they also minimize the number of human errors and increase user satisfaction. But this does not happen by itself. The effective user interface is the result of the developer's understanding of the need to pay attention not only to the data but to the user, his tasks, and activities.

Here are some of the most significant benefits of a good user interface

- reduction of losses of productivity of users at system implementation;
- faster restoration of the lost productivity;
- reducing the number of human errors;
- improving the morale of users;
- reducing the cost of system support;
- reduction of costs for UI redesign.

2. Generalization of evaluation criteria for the user interface

Each hardware or software product is a set of different functions. This provides users with various controls. Therefore, it is necessary to have standards for evaluating the technology or products of the user interface. Obviously, UI directly depends on the task that solves the software, data input and output. However, all this data can be presented to the user in different forms. The success of solving the problem in software development depends on how functional, clear and user-friendly the interface is.

If the interface forces its users to make mistakes, then this interface is bad, at least it is worse than the interface that helps to avoid such mistakes. The UI design process is most influenced by the designer's own perception of clarity, convenience, beauty. Therefore, it is very important to assess the quality of UI. Carrying out such assessments in the early stages of the design process avoids numerous errors, miscalculations, deviations of the software by the end-user.

There are many ways to assess the quality of UI. The general model of the software evaluation process includes the stages of determining the quality requirements. In other words, the interface of a software product can be evaluated based on various standards, quality indicators and interface attributes. Although the evaluation of the quality of the user interface process is quite subjective and difficult to formalize, it is safe to say that a good interface should ensure the efficiency and productivity of the user's work.

Utility, usability, desirability are three things that should underlie the design of any software product [5, 6]. Taking into account the needs and expectations of users from the design of the interface, we can identify certain recommendations that should be followed and based on them to edit the user interface.

- *Display the real world in the user interface.* The developer should try to reflect the language and concepts that users use in the real world, based on what their target audience is. Providing logically structured information and engaging users' expectations from their actual experience will significantly reduce cognitive load and facilitate the use of the software product.
- *Standards and consistency.* Developers of the user interface must ensure that conditional standards for both graphical elements and terminology are maintained. For example, an icon that represents one category or concept should not represent another concept if it is used multiple times in a program or site.
- *Efficiency and flexibility.* As the frequency of use increases, there is a need for fewer interactions that provide faster navigation and ease of use. This can be achieved with abbreviations, function keys, hidden commands, macros. A good solution would be to allow users to customize or adapt the interface to their needs so that frequent actions can be performed with more user-friendly tools.
- *Recognition.* Human attention is limited, and we are only able to store a few items in our short-term memory at a time. Because of the short-term memory limitations, designers need to provide an interface so that users can simply use recognition instead of remembering the information they remember in fragments. Recognizing something is always easier than remembering it because recognition involves the perception of signals that help us penetrate our vast memory and allow relevant information to appear.
- *Documentation and reference.* In an ideal software product, users navigate the system without resorting to documentation. However, regardless of the type of solution, documentation is still required. When users need help, it's important to find it easily. According to the task, the documentation should be designed in such a way that it guides users through the necessary steps to solve the problem they face.
- *Error prevention.* When designing, developers aim to minimize potential errors. Ordinary users should not be encouraged to identify and correct problems that may go beyond their level of knowledge, for this purpose the work of testers is provided. Eliminating or flagging actions that can lead to errors are two possible ways to prevent errors.
- *Freedom of action of the user.* A good solution is to create a digital space where the user can take steps backward, including undoing and redoing previous steps.
- *System status.* It is important to inform users about the current state of the software product, whether it is "download", "search", "recovery" or other variations. Easy to understand and clearly visible status should be displayed on the screen for a reasonable period of time, in particular, while the system is in the appropriate state.
- *Minimalism.* The point of this tip is to minimize clutter in the interface. All unnecessary information competes for limited resources of the user's attention, which can prevent the search for relevant information in the user's memory. Therefore, the display should be limited to the necessary components for current tasks, while providing clearly visible and unambiguous means of navigating to other content.

Based on these recommendations, the quality UI can be based on a number of criteria. These criteria vary from author to author [2, 7, 8]. We summarize the list of these criteria and present the following characteristics of software quality assessment in the table 1.

Scientists [2, 9] offer a sequence of stages of designing an ergonomic user interface, such as

Table 1. Criteria for evaluating the user interface.

Group of criteria	Criterion	Description
Functionality	Suitability	Compliance of the program with the declared set of functions and the ability to perform relevant tasks
	Accuracy	Software attributes that require the correctness and relevance of results or effects
	Interoperability	The ability of software to interact with specific systems, the ability to integrate it with other applications and services
	Concordance	Compliance of software with standards, agreements and laws
	Securicity	The ability of a program to prevent unauthorized access, accidental or intentional alteration of its data
Reliability	Meturity	Frequency of software failures caused by errors in its design and development
	Fault tolerance	Ability to maintain a certain level of performance in cases of software errors or violations of a particular interface
	Recoverability	Ability to restore functionality and data that has been damaged due to failure of the application or service
Usability	Understandability	Measured by the user's efforts to understand the logical concept and applicability of the software
	Learnability	It is measured by the user's efforts to learn how to use an application or service
	Operability	It is measured by the user's effort to use and operational control of the software
Efficiency	Time behavior	Determined by the response time and processing of functions by the application
	Resource behavior	Determined by the amount of OS resources used and the duration of such use
Portability	Adaptability	Ease of adapting the software to different operating conditions other than those provided for this application
	Installability	The effort required to implement the software in a specific environment
	Replaceability	Simplicity and complexity of using a software application instead of another software tool

- specification of design objective;
- analysis of tasks and function of the interface;
- analysis of requirements and preferences of the operator;
- selection of rules of interface design;
- development of the structural scheme;
- rapid prototyping;
- development of experimental evaluation of the prototype interface;
- analyses of tests results and develop recommendations of finalize;
- creating of functional software;
- a comprehensive experimental evaluation of the interface.

3. Problems of developing ergonomic user interfaces

Today, ergonomics of software as a science is still at the stage of initial development. But active research in this area has already produced many useful conclusions regarding the factors affecting the performance of software use. As experience shows, many interfaces are unsatisfactory [7, 8, 10]. This is because they are too narrow-profile and require a fixed combination of user skills. A good interface should serve different users. One of the main problems of ergonomic UIs creating is the construction of a user‘s activity model. This framework can help to receipt of estimates of error-freeness, resource consumption indicators and variant analysis of alternative methods of data processing [11].

In general, we can distinguish between human-oriented and computer-oriented approaches to the development of user interfaces. However, any of these approaches must be the result of an analysis of the user's tasks. From ergonomic principles [12] it is possible to understand why modern software cannot be used productively enough in the context of various and unstructured tasks. Considering the typical modern software products, we have identified some shortcomings, such as

- *No integration.* To get the desired results, end users often have to combine the work of several applications. Each application has its own data format requirements. This usually requires manual user intervention. For example, using a text editor, output data from one program to a specific input format for another. Another problem is that once data has been imported, its structure is often lost. Each program and the operating system itself has its own requirements for data formats and modes of their import. Some programs have several such modes that require the user not only the relevant knowledge, but also an understanding of the current application of the desired mode. This is a high cognitive load and therefore a source of error.
- *Loss of context.* During the task, the user finds himself in a situation where the required data is not immediately available. They must be obtained in some way outside the context of the current task. Many systems switch only when the expected task enters a quiet state. Perhaps instead of suspending such a task, it should be closed. This means that the context of the unfinished task is lost and the user must explicitly return it during recovery.
- *Mysteriousness.* The exact forms or formats of data that are required for commands or functions of the program, often have to look for in huge and difficult to interpret manuals.
- *Swiss Army Knife Syndrome.* Many features of the software package, such as e-mail, finding a letter (searching), archiving it (storing it), composing a letter (editing), and so on. Such functions are in fact exhausted versions of much more general functions that happen to be applied to one particular context. This can lead to a huge duplication of functionality and increased inconsistency, causing constant danger of confusion in the mode and deepening the overall complexity of the user interface.

It may seem that the shortcomings were deliberately designed for the purpose of preventing users from making effective use of technology. However, developers never deliberately create interfaces for everyday use with flaws. Design flaws are identified by real-world testing, which detects uses that have not been properly taken into account at the design stage. Disadvantages are the sins of omission (not taking into account something), not the sins of committing (intentionally making it difficult to use something). Exceptions may be software products designed for scientific purposes to study the impact of these deficiencies on users.

The existence of such shortcomings imposes a large cognitive load on the user. This distracts him from the real task that needs to be done. As a result, numerous user errors become inevitable. This is especially true for routine tasks, in which computers easily outperform people. Peoples start making mistakes due to a drop in attention during repetitive tasks. But a significant portion of the effort in using computers as an intelligent tool is a task without intelligent content. Such as data conversion formats. The current situation forces users to constantly spend much of their attention on the low-level aspects of communication. Although computers are much better than humans at tracking the exact state of a task, the user is forced to store the details of the context in their own memory, not the computer.

Mistakes in most cases are just "stupid" mistakes that cause irritation and loss of time but do not cause much harm. From time to time, however, a well-understood user error is costly, causing incorrect results, or the loss of a large amount of work, or even the irreversible loss of information, which causes great suffering [13]. Even without such troubles, the total time users spend guessing, puzzling, or trying to figure out something rather trivial is impressive. However, these "inevitable" mistakes are inevitable only because the simplest principles of ergonomics are not applied to the design of the user interface. An important prerequisite for a good interface is that the system appears to the user as an integrated system with a single interface, rather than a set of different interfaces, one for each individual function of the system, even if each individual interface is well-designed. This, in turn, requires that a single conceptual framework underpin the entire system, a framework in which a variety of programs can be integrated naturally.

4. Examples of disadvantages in the ergonomics of user interfaces

Good UI design makes user interaction with the application or site simple, intuitive, efficient, and smooth. A bad user interface can be annoying or directly prevent users from continuing to work. The shortcomings in the examples below may seem comical or downright annoying, but they are still found in UI design.

Use of intuitive notation.

Changing the language is the first thing a user wants to do if they open a site or software they can't read (see figure 1). It also makes sense to make this option as simple and optimal as possible to choose before performing any other actions such as login, registration, password change. The most successful is the idea of using intuitive notation. A globe icon or language icon will greatly facilitate the search for the user. However, caution should be exercised when using country flags. This is because common languages or branched dialects are easy to confuse.

Choosing the right tool to work

The basis of interface design is choosing the right tool to work with. This should usually mean respect for common symbols and the use of familiar controls. For example, for clarification, flags are used when it is possible to mark several options or radio buttons (see figure 2). In this case you should use the plus and minus buttons, which allow user to adjust the number of the desired item to the his/her choice .

Ambiguity

At first, it is worth noting that users are accustomed to marking checkboxes themselves, rather than removing already selected ones. However, in this case, the problem of the interface is the ambiguity of the interpretation of concepts. To remove an ingredient in order, do you need

Figure 1. The problem of language choice.

Figure 2. Inappropriate controls.

to uncheck or leave it? This confusion misleads the user and causes several misunderstandings and issues (see figure 3). That is, uncheck no salad to remove the salad. In this case, it is better to change the text related to each of the checkboxes to a clearer and simpler one.

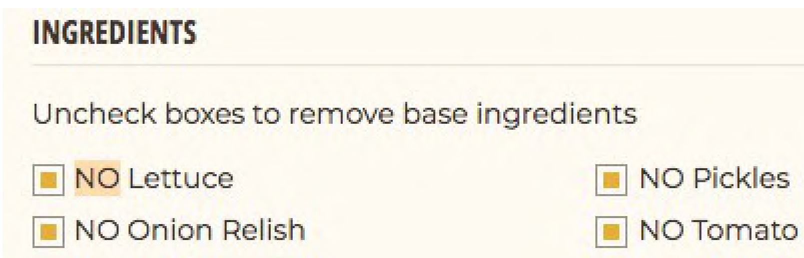

Figure 3. Ambiguous interpretation action of the checkbox.

Excessive choice of options

Drop-down lists to choose from numerous items are not a good solution. It is much easier for a user, for example, to enter his year of birth than to flip through a long list over the years. Regarding the choice shown in figure 4, developers should consider whether to use drop-down lists at all or to change the approach to filling out the form. In the best case, suggest the user enter data from the keyboard yourself, and only then, according to the entered combination of words or symbols to give examples of filling options.

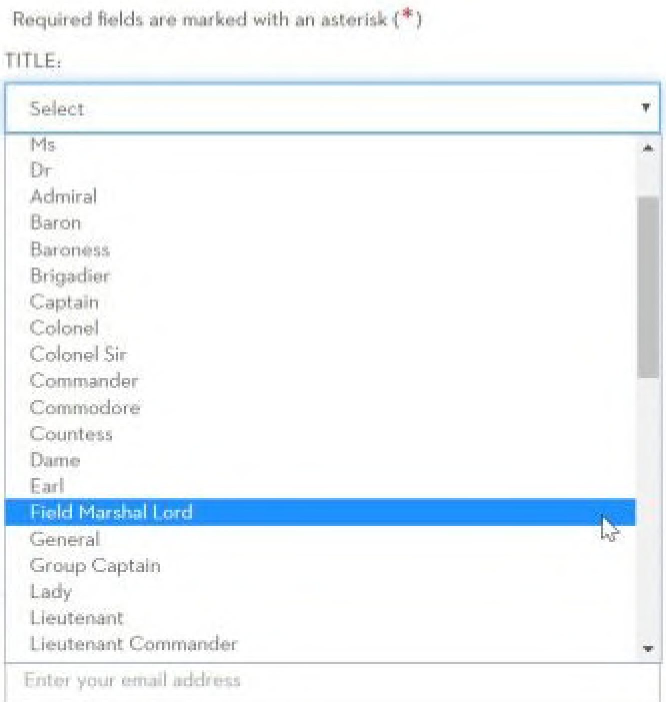

Figure 4. The disadvantage of a long list.

Thinning of the contents

To find out the entire history of the company, the user needs to go to five different web pages, although it would be much more ergonomic to form the whole concept of the company in one page (see figure 5). This thinning of the content in different sections forces the user to "wander" on the interface and as a result to spend extra time. The developers of this site should expand the content of one page "About" at the expense of the content of nested child pages so that the user visiting this site received complete information about the company without making unnecessary transitions on the pages.

5. Conclusions

The problem of designing user interfaces is currently relevant. Therefore, to facilitate the work with the software product, developers need to think about and create an ergonomic user interface that would accordingly perform all the tasks assigned to it. This paper argues the importance of ergonomic interface, the benefits of a good UI, such as reducing the overall cost of system support or redesign, a significant reduction in the number of human errors during use.

Given the user needs, expectations, and expectations of the interface design, the paper identifies strong recommendations that should be considered and included in the editing of the user interface. These include well-understood documentation and usage tips that unscrupulous UI developers can ignore or the user's freedom of action based on digital space with possible return steps. It is also recommended to resort to minimalism, which includes the definition of

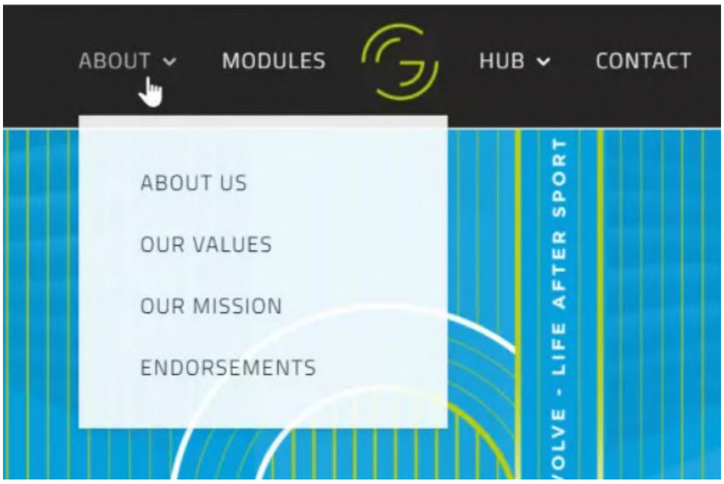

Figure 5. Disadvantage of a multi-page website.

the primary functions of the interface and the elimination of cluttered clusters of components that are not necessary for current tasks. These recommendations and advice are the basis for a number of criteria.

The article contains the characteristics of software quality assessment, namely summarizes the criteria for ergonomics of the user interface based on a review of already written scientific papers. All sixteen criteria are divided into five general groups: Functionality, Reliability, Usability, Efficiency, Portability, which give an understanding of what this or that characteristic refers to.

Considering the published scientific works, the sequence of stages of designing an ergonomic user interface is noted by scientists. One of these steps is the analysis of test results and the development of recommendations for refinement, which can already assess the problems that may arise during the development of ergonomic user interfaces. Therefore, the article lists some typical shortcomings in modern software products that have not been removed. In total, 4 shortcomings were noted: Swiss Knife Syndrome, Mystery, Loss of Context, Lack of Integration, which are reasonably recommended to eliminate when refining the UI.

Ergonomic criteria should take into account possible errors of user users. Therefore, ergonomic applications should be interactive, intuitive, interruptible, ”indulgent” to mistakes. For a practical picture of the problems of the non-ergonomic user interface, the work contains illustrated examples of shortcomings that are still encountered by users and significantly affect usability. Ordinary people who use these software products face problems and misunderstandings. Instead, the authors drew attention to ways to correct existing errors and changes that would improve user interaction with the software interface. This seemingly understandable problem with the default interface language mismatch is easily eliminated by replacing words with intuitive notations that successfully implement the basic functions of the user interface. An efficient interface is the result of the developer’s awareness of the need to pay considerable attention not only to the data that the user will work with, but also to the actual details of the interface.

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Data mining of the healthcare system based on the machine learning model developed in the Microsoft azure machine learning studio

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Data mining of the healthcare system based on the machine learning model developed in the Microsoft azure machine learning studio

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Abstract. This article presents data mining, which is based on the methods of mathematical statistics and machine learning, describes the features of applying regression analysis methods in the machine learning systems. The developed machine learning model includes the regression analysis modules based on the Bayesian linear, artificial neural network, decision tree, decision forest, and linear regressions. In the process of applying this machine learning model, using the mentioned algorithms, the corresponding regression models were constructed and their comparative analysis was performed, the results were analyzed. The results obtained indicate the feasibility of using data mining in the medical research using machine learning systems. The presented methods can serve as a basis for strategic development of a new directions of the medical data processing and decision-making in this field. We have identified the prospects for further research aimed at applying data mining methods to the healthcare system, namely, clustering, classification, anomaly detection.

1. Introduction

In today's world, healthcare costs are rising rapidly, primarily due to epidemic problems caused by coronavirus disease COVID-19, demand for quality health care, aging population, increasing number of people suffering from chronic diseases with long-term disease, etc.

Over the past three years, the "Value in healthcare" World economic forum project has been an important source of new thinking and research on how to improve the healthcare system, implemented in collaboration with the Boston consulting group (BCG) [1–3]. Since the launch of the project in July 2016, the main provisions for the transformation of the healthcare system based on cooperation with project stakeholders have been developed.

The report on the results of this project dated april 27, 2017 identified the fundamentals of improving the healthcare system (Value in healthcare: laying the foundation for health system transformation) [1]. The report notes that the approach to health care is largely focused on guidelines for scope and processes, rather than just true value to patients (figure 1).

The benchmarks of this system are the quality of medical services and their cost, which is important for the patient, not their volume. The components that are the basis for the

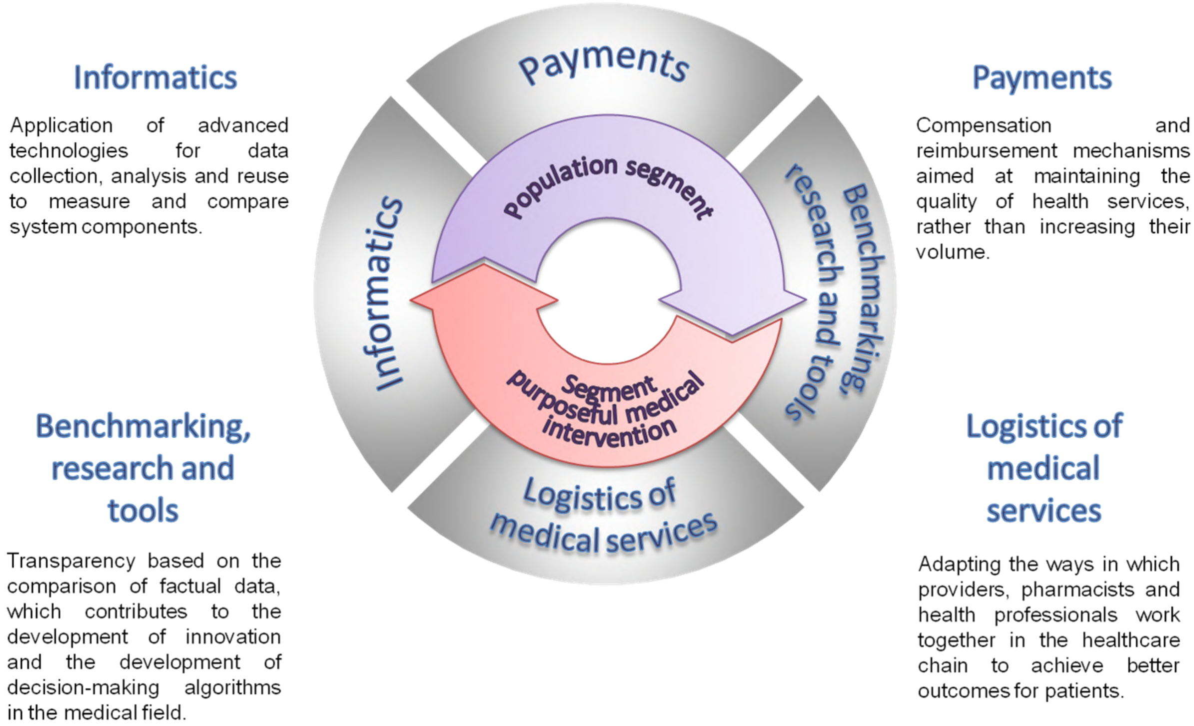

Figure 1. Comprehensive patient-value-oriented healthcare system [1].

transformation of the healthcare system are computer science, payments, benchmarking of research and tools, logistics of medical services (figure 1). An approach based on the values described in this project should start with measuring results that are relevant to a particular segment of the population. The results of the measurements are then used to adapt health services for this segment of the population through the path of patient care, based on improving the quality of health services, reducing their cost, rather than increasing the amount of care. The focus in these cases is on adapting the methods of providing medical services to the needs of the population and cooperation in the chain of services of providers, pharmacists and medical partners.

The second report of february 12, 2018 "Value in healthcare: mobilizing cooperation for health system transformation" is devoted to the areas of mobilization of cooperation to transform the health care system, namely [2]: new models of cooperation between stakeholders, new standards for informatics in healthcare, new areas of leadership.

In accordance with the subject of our study, we will consider in more detail the new standards for health informatics proposed in this report [2]. It is also important for the patient to have access to their medical data in order to have a more holistic view of their own health and a growing willingness to monitor their own statistics of vital situations. Access to medical data sources is also necessary for the effective operation of health care providers, investors, government agencies, researchers, scientists and others. Technological developments in computer science today meet these needs. However, in this way there is a problem of developing global standards for data transmission and processing. For reasons related to the rapid development of medical technology, the establishment of such standards is increasingly urgent.

One of the most important elements of this project is the development of an integrated information and digital health care system that will allow easy and convenient collection, exchange and analysis of data in healthcare [2]. Its components are not only hardware and software, but also the standards governing such systems, organizational capabilities necessary for their effective use. If the goals of the health sector are to anticipate the risk of disease, ensure proper prevention, and accurately target treatment pathways to meet the specific needs of populations, then access to comprehensive data from a significant number of patients is a prerequisite. Determining generally accepted global standards in health informatics is key to creating a genuine, people-centered healthcare system. Setting standards may seem like a technical challenge, but it is another critical mechanism for health cooperation.

The development of information and digital technologies in the field of healthcare contributes to the evolution of medical knowledge. For example, it is now possible to modify highly targeted therapies for people with specific genetic profiles. But the use of genetic data to select treatments requires access to large data sets from different sources to generate statistically sound recommendations based on them [2].

New approaches to data collection and exchange, such as blockchain, have the potential to ensure confidentiality and security by ensuring transparency of data transfer and audit of their use [2]. Progress in the field of artificial intelligence, in particular machine learning, makes it possible to create information and digital systems of machine learning, to develop automated tools to support decision-making.

Thus, in order to solve global problems on the way to building sustainable healthcare systems at this stage, the information component should be provided by: standardization of medical informatics; development of artificial intelligence, in particular, machine learning; benchmarking of data mining tools, in particular, statistical.

The application of statistical methods to the processing of medical data in recent years has become increasingly popular and is the subject of research by many scientists. This situation is due to the rapid development of information and digital technologies and the generation of significant amounts of data in the field of health care. The need for big data processing, the selection of statistical methods for their processing, the use for this purpose of machine learning and data mining in modern medicine contribute to the innovative search for researchers in this field.

C. Prakash and R. K. Saini, based on studies of large statistical samples, reveal the features of the application of data mining for forecasting, which is considered as a tool to combat COVID-19 [4].

R. Puri, D. Giri, S. R. Srinivasarao, U. Gawande and D. Hawale, based on a set of data obtained from information systems, hospitals explore the possibility of using data analysis techniques to identify and manage risks in the field of healthcare [5].

S. M. Birjandi and S. H. Khasteh conduct a comparative analysis of data mining methods used in medicine [6]. They analyze various methods of data mining, including decision tree, random forest, K-means clustering, reference vector machine, logistic regression, neural network, naive Bayes and association analysis various diseases [6].

N. Lavrac explores the approaches to machine learning used in the analysis of medical data [7]. He reveals the differences between symbolic and subsymbolic methods of data analysis. This researcher presents selected indicators of performance evaluation and presents their application in medical prognosis [7].

A. Garg and V. Mago analyze the scientific literature on the study of various methods of machine learning in medicine, including medical applications [8].

L. J. Muhammad, E. A. Algehyne, S. S. Usman, A. Ahmad, C. Chakraborty and I. A. Mohammed study the application of machine learning, data analysis, deep learning, decision tree model, support vector model, Bayesian model and artificial intelligence to diagnose and predict the condition of COVID-19 patients and the spread of this infection [9]. Based on a set of epidemiological data, these researchers analyze and develop machine learning models to predict COVID-19 infection [9].

W. Li, Y. Chai, F. Khan, S. R. U. Jan, S. Verma, V. G. Menon and X. Li analyze the features of the application of machine learning methods used for big data research in the field of health care [10].

Machine learning technologies are increasingly being used in healthcare and are being studied by scientists around the world. Cognitive computing based on machine learning allows you to reproduce neuromorphic architectures of artificial intelligence, generate high-performance parallel algorithms for modeling processes and systems, solve problems of fuzzy logic, unstructured data, big data, soft computing, etc. [11]. I. Malik and T. Knignitska in their study described the main methods of machine learning that can be used for statistical processing of medical data, built a predictive model and predicted the likelihood of cardiovascular disease in men and women, performing a comparative analysis of four algorithms of machine learning [12]. Possibilities and prospects of application of machine learning methods in biomedical engineering were studied by O. Repyah and O. Biloshitska. They identified the following main areas of research: "analysis of biomedical signals, image analysis, modeling of systems for monitoring patient health and ancillary systems to improve the efficiency and speed of machine learning models" [13]. Foreign researcher C. W. Wang proposed a composition of metaalgorithms of boosting, adaptive resampling and aggregation (ARCing) and bootstrap aggregation (improving stability and accuracy) (bagging) in the article "A new ensemble method of machine learning for classification and prediction of gene expression data") [13]. The ensemble of meta algorithms (New1) Data bootstrapping + Arcing skeleton and (New2) Data bootstrapping + Boosting skeleton is used by him in order to provide reliable and accurate classification of tumors necessary for successful cancer treatment [14]. Studies have confirmed that his proposed machine learning is much more effective than existing methods, as it achieves high accuracy of gene expression 79.03-100%. According to the results of testing on 12 datasets, the best ensemble is (New2) Data bootstrapping + Boosting skeleton (accuracy 83.87% -100%) [14].

The works of scientists presented in the article do not exhaust all research in this field. However, scientists have not considered a machine learning model developed in the Microsoft azure machine learning studio that includes regression analysis modules based on Bayesian linear regression, linear regression, neural network regression, boosted decision tree regression and decision forest regression.

The aim of the study is to data mining of the healthcare system based on the model of machine learning developed in Microsoft azure machine learning studio, which includes modules Bayesian linear regression, linear regression, neural network regression, boosted decision tree regression and decision forest regression.

2. Methods of the research

One of the most widely used statistical methods is regression analysis. The chain of regression analysis technologies requires the use of other sections of mathematics and computer science, which causes a number of interrelated problems in the process of its use.

This study used data from the "Medical cost personal datasets", which are publicly available on the Kaggle platform and were obtained on february 21, 2018 [15]. The data set is presented in CSV format, it consists of 7 columns, 1338 rows (table 1). Data were tested for multicollinearity. It is established that multicollinearity is absent. The dataset contains the fields described in table 2.

In order to build a model of machine learning based on regression algorithms, we used the Microsoft azure machine learning studio [16]. Microsoft azure machine learning studio is a visual development environment that includes datasets and analysis modules. This environment supports sharing capabilities designed to create, test, and deploy predictive data analysis solutions.

Table 1. Personal data of medical expenses [15].

age	sex	bmi	children	smoker	region	charges
19	female	27.90	0	yes	southwest	16884.92
18	male	33.77	1	no	southeast	1725.552
28	male	33.00	3	no	southeast	4449.462
33	male	22.71	0	no	northwest	21984.47
32	male	28.88	0	no	northwest	3866.855
31	female	25.74	0	no	southeast	3756.622
46	female	33.44	1	no	southeast	8240.59
37	female	27.74	3	no	northwest	7281.506
37	male	29.83	2	no	northeast	6406.411
...	...	...	...	...	...	...

Table 2. The structure of the "Medical cost personal datasets" [15].

Field name	Content	Data type	Data analysis: graphical representation
age	age of the main beneficiary	numeric	figure 2: 1
sex	gender of the insurance contractor (woman, man)	string	figure 2: 2
bmi	body mass index (kg/m^2)	numeric	figure 2: 3
children	number of children on health insurancenumber of dependents	numeric	figure 2: 4
smoker	smoking	string	figure 2: 5
region	US resident residential area (northeast, southeast, southwest, northwest)	string	figure 2: 6
charges	individual medical expenses accrued under health insurance	numeric	figure 2: 7

We will build regression models using machine learning algorithms Microsoft azure Bayesian linear regression, linear regression, neural network regression, boosted decision tree regression and decision forest regression (table 3).

3. Results and discussion

We will conduct a study of the impact on charges (individual medical expenses accrued under health insurance), predictors: age (age of the main beneficiary), sex (sex of the insurance contractor), bmi (body mass index), children (number of children on health insurance)/number of dependents), smoker (smoking), region (residential area of residence in the USA).

As a regression Y we determine charges. As regressors we choose X1 - age, X2 - sex, X3 - bmi, X4 - children, X5 - smoker, X6 - region.

All Microsoft azure algorithms presented in table 3 are controlled machine learning algorithms, with training on a test data set, which we have provided in the process of developing a system of regression models. The scheme of the machine learning model based on the regression construction algorithms presented in table 2 is presented in figure 3.

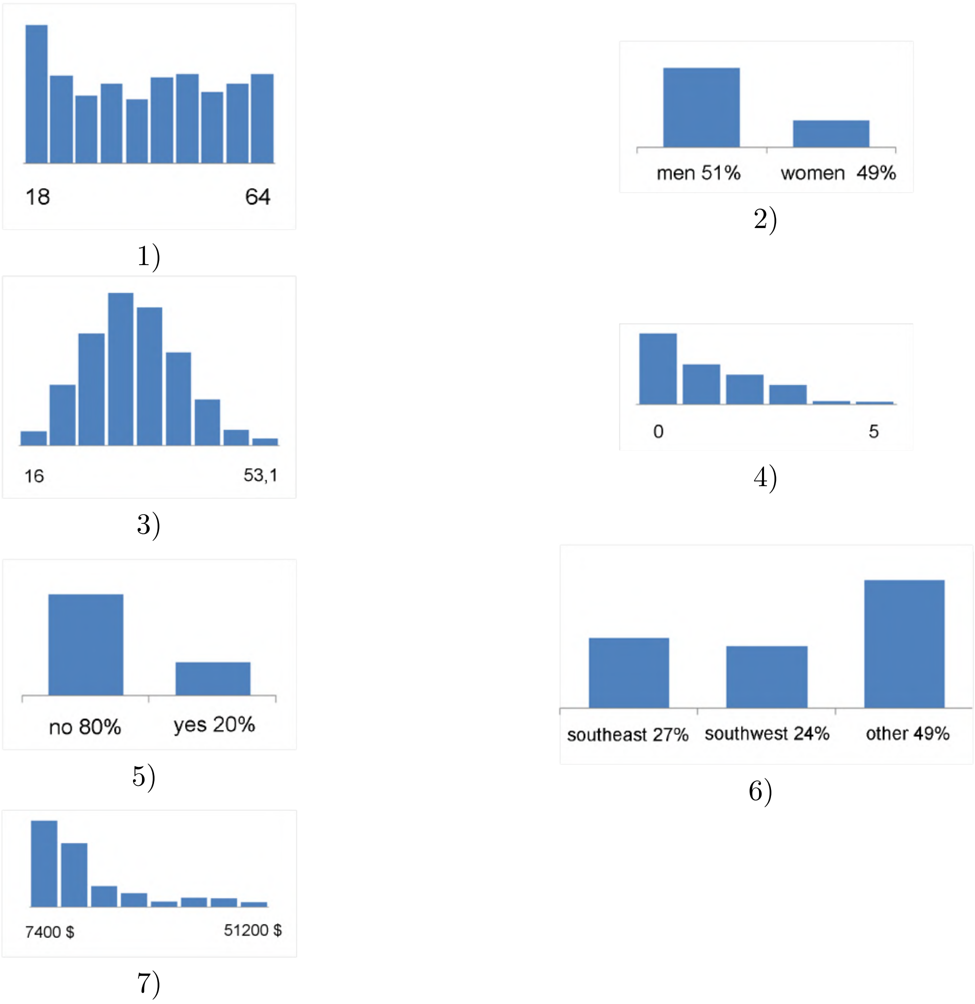

Figure 2. Graphical representation of "Medical cost personal datasets" [15, 16].

Let's describe the model presented in figure 3. The dataset model unit loads the data for further processing. The Edit metadata block allows you to edit metadata by selecting columns from the dataset. The Split data module divides the rows of the data set using the settings into two different sets: for training and model testing.

Modules Bayesian linear regression, neural network regression, boosted decision tree regression, linear regression, decision forest regression provide the creation of regression models using the above algorithms (figure 3).

Training of regression models is implemented using the Train model block on the training data set (figure 3).

The developed regression models are tested using the Score model block on the test part of the data (figure 3).

The Evaluate model evaluates the developed regression models using standard indicators: mean absolute error (MAE), mean square error (RMSE), relative absolute error (RAE), square relative error (RSE), coefficient of determination (R^2) (figure 3).

The Execute R script unit is responsible for executing the R script of the machine learning experiment in order to extract the performance indicators of the model (figure 3).

Using the Add rows block allows you to add a set of rows from the input dataset to the end of another dataset. It was used by us in order to obtain comparative statistics of performance

Table 3. Regression algorithms of machine learning Microsoft azure [16].

Algorithm name	Algorithm characteristic	Accuracy	Training time
Bayesian linear regression	"Bayesian approach to the construction of linear regression is based on the use of the Bayesian rule to clarify the probability of the hypothesis. Preliminary data on parameters are consistent with the probability function for the formation of parameter estimates"	–	moderate
Linear regression	"Establishing a linear relationship between one or more independent variables and a numerical result, or dependent variable"	–	quick
Neural network regression	"An artificial neural network is built on the basis of a statistical model using adaptive scales and approximation of nonlinear input functions"	high	–
Boosted decision tree regression	"Used to create an ensemble of regression trees by deployment. Deployment means that each tree depends on the previous trees. The algorithm learns by establishing the remnants of the trees that preceded it. Thus, the deployment in the ensemble of decision trees tends to increase accuracy with some small risk of less coverage"	high	moderate
Decision forest regression	"This regression model consists of an ensemble of decision trees. Each tree in the decision forest generates a Gaussian distribution as a forecast. Aggregation is performed on an ensemble of trees, to find the Gaussian distribution closest to the combined distribution for all trees in the model"	high	moderate

indicators of the developed regression models and to provide convenient data analysis (figure 3).

Let's analyze the obtained results of construction of regression models on the basis of comparative statistics (table 4).

According to the average absolute error (MAE), the closest to the actual results data forecast was built using the algorithms decision forest regression (2688.50) and boosted decision tree regression (3074.97), the worst result for this indicator 8608.14 was obtained using the neural network regression algorithm. Higher average absolute errors, at about the same level, were obtained as a result of the construction of linear regression (4035.00) and Bayesian linear regression (4043.11).

The obtained mean square error (RMSE) values also indicate the superiority of the decision forest regression (4891.34) and boosted decision tree regression (2688.50) algorithms. As previously estimated, the values of linear regression (5875.64) and Bayesian linear regression (5870.81) are higher than the experimental RMSE values of the decision forest regression and boosted decision tree regression algorithms and are approximately at the same level. The worst value is the result of the neural network regression (11704.30) among the data estimates of the RMSE indicator.

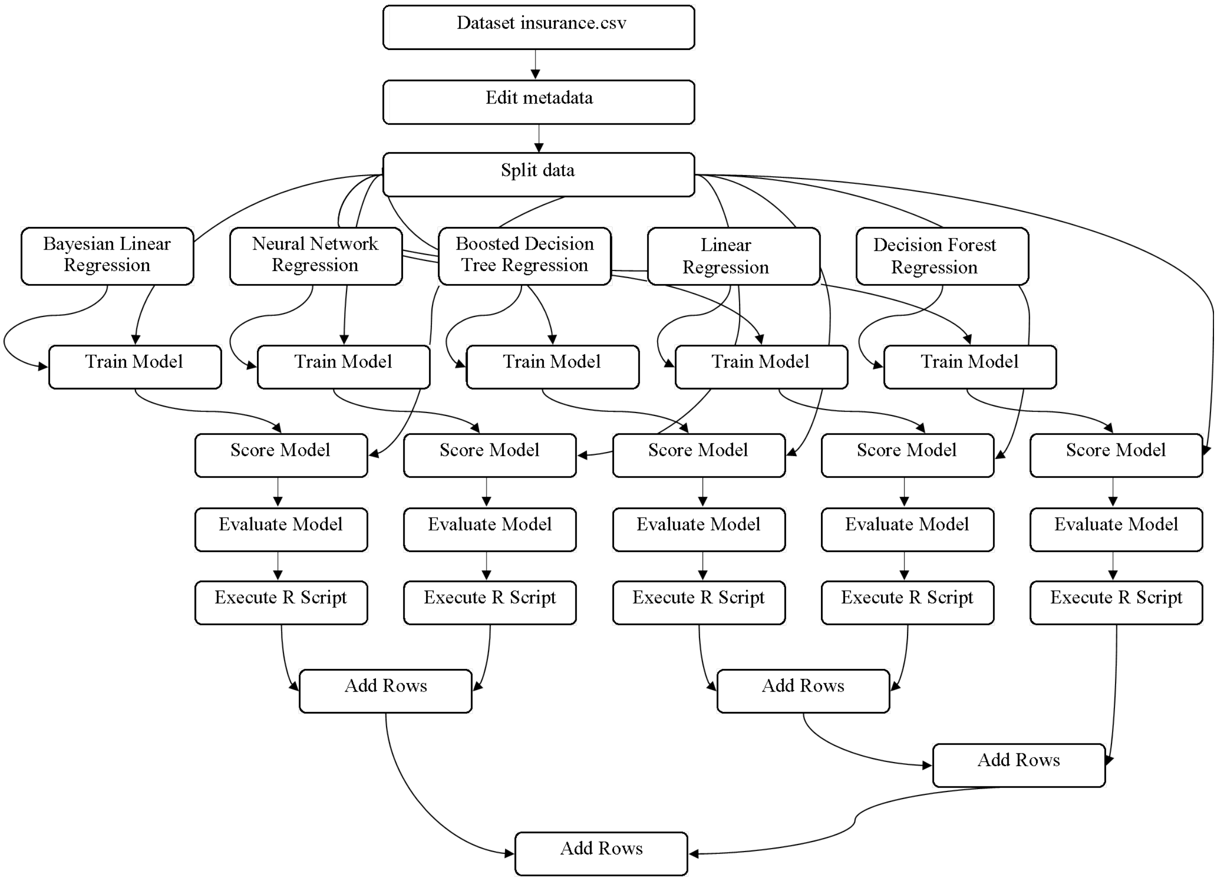

Figure 3. Scheme of machine learning model based on regression algorithms [16].

In terms of relative absolute error (RAE) and square of relative error (RSE), the priority of estimations of regression modeling algorithms remains the same as in the two previous results. It should be noted that the worst indicators of neural network regression (RAE = 0.98, RSE = 1.00), which characterizes the approximation of the error value to the average value of the resultant trait.

The highest value of the coefficient of determination (R^2) was obtained by testing a model built on the algorithm decision forest regression (83.51%), slightly lower than the value of R2 obtained by the algorithm boosted decision tree regression (82.5%). The coefficient of determination characterizes the part of the variance of the dependent variable due to the influence of independent variables, ie the magnitude of its change under the influence of independent variables. The regression models based on this value of the coefficient of determination can be considered adequate. Models obtained using linear regression and Bayesian linear regression are also adequate, as their coefficient of determination is 74.75% and 75.8%, respectively. The value of the coefficient of determination $R^2 \approx 0.002$ testing a model built on the algorithm neural network regression indicates that this model is inadequate.

Therefore, the error estimates obtained as a result of testing the developed regression models according to the above algorithms are consistent with the magnitude of error values. The model that is closest to the actual data is the machine learning model, built on the algorithm decision forest regression. It is estimated that a regression model based on the boosted decision tree regression algorithm is close to it. Slightly lower values were obtained in the process of building regression models using the linear regression and Bayesian linear regression algorithms.

Table 4. Estimation of the developed regression models by means of standard indicators [16].

Algorithm	Mean absolute error	Root mean squared error	Relative absolute error	Relative squared error	Coefficient of determination
Bayesian linear regression	4043.118891	5870.810291	0.46089	0.252041	0.747959
Neural network regression	8608.141839	11704.303673	0.981273	1.001764	0.001764
Boosted decision tree regression	3074.973992	4891.34106	0.350527	0.174957	0.825043
Linear regression	4035.002081	5875.638426	0.459964	0.252455	0.747545
Decision forest regression	2688.501275	4747.376399	0.306472	0.164809	0.835191

The model built using the neural network regression algorithm is inadequate and unusable. This result indicates that the application of this algorithm requires additional settings, careful preliminary preparation of data sets. It is also possible to recommend using a different regression-based algorithm based on neural networks.

4. Conclusion

Thus, as a result of the analysis of data on the basis of methods of mathematical statistics and machine learning the following is done: the peculiarities of application of regression analysis methods in machine learning systems are characterized; a model of machine learning system was developed, which includes regression analysis modules based on Bayesian linear regression, artificial neural network, decision tree deployment, decision forest and linear regression. In the process of applying this model of machine learning, appropriate regression models were built, the results obtained on the basis of these algorithms were analyzed and their comparative analysis was performed. The results of the study indicate the feasibility of using data mining in medical research using machine learning systems. The presented methods can serve as a basis for the strategic development of new areas of medical data processing and decision-making in this area.

Modern medicine requires non-standard approaches to data mining, integrated application of methods, their modifications, the use of an ensemble of methods to enable the processing of large data sets in information and digital systems. Statistical methods of data analysis are a reliable tool of evidence-based medicine that increases the cost-effectiveness of medical technology.

The main goal of building an integrated information and digital health system focused on people is to support the fundamental model of patient care and innovative value-oriented model of health care. It should identify vectors for the systematic improvement of the health care system, in which continuous analysis of data on health care outcomes and costs leads to more accurate identification of key segments of the population and the development of individual measures to optimally ensure the functioning of these segments.

The information infrastructure to support this cycle of continuous improvement requires the development of data systems and architectures based on standards for data collection, consolidation of data from various sources, display, exchange, access to them for benchmarking and mining. Such measures will enable the exchange of data between health systems and other stakeholders to accelerate innovation. Also, the need to build an integrated information and digital health care system is due to the need of clinicians and researchers in hospitals, academia, insurance, pharmaceutical, medical and analytical companies to conduct intellectual analysis of large, structured, semi-structured and unstructured data sets. The development of health informatics standards will also accelerate the development of sophisticated analytical tools (such as automated decision support tools) that generate knowledge based on datasets for clinical methodology, research, and development in the medical sciences.

The obtained results allowed to determine some areas of further research in the application of data mining methods in the health care system, namely, the use of machine learning systems for clustering, classification, detection of anomalies and more.

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Calculation of storm fuel supply of a seagoing vessel: solving professionally-oriented tasks using cloud services

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Calculation of storm fuel supply of a seagoing vessel: solving professionally-oriented tasks using cloud services

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Abstract. The information and communicative competency today is an integral part of professional training in any sphere. Due to the fact that nowadays big amount of work is done or monitored in the remote mode the requirement is stipulated for every specialist to be able to use digital technologies professionally. For a future seafarer it means, first of all, the ability to use modern technologies as the information and data resource and also it presupposes the ability to work with software libraries, to create data bases, to perform necessary calculations by means of cloud services inclusive. This component is of extreme practical importance as it enables the satisfaction of the social mandate to prepare future seafarers for the living in the information environment. The task is quite challenging so it requires the adequate knowledge level. That is why the main objective of the course "Information technologies" together with other subjects within the curriculum for the professional training in maritime academy is to develop the reliable scientific and methodological grounds for the realization of any professionally related tasks of future merchant fleet officers. Specially selected tasks acquaint cadets with information technology in terms of implementing the solution of applied professionally oriented tasks, such as navigating the course, determining the location of the vessel, calculating stocks for the trip, etc. Therefore, the obligatory elements of the tasks are: construction of mathematical (computer) models;analysis of possible solutions to the problem; of technological processes, taking into account all factors influencing the process and methods of decision-making;implementation of mathematical models of problems in spreadsheets. This article proposes a strategy for solving an applied problem using an information-modeling approach to the analysis and evaluation of the technological process, namely, the algorithm for calculating the required voyage and storm fuel reserves of a marine vessel. Both office spreadsheets and cloud services were used to implement the mathematical model for solving this problem. The use of "cloud computing" technologies in the training of seafarers is due to the fact that, firstly, while on board, the master or ship mechanic can perform some components of their work, especially joint projects, in modern services, and secondly, these technologies, supporting traditional forms of education, is a new stage in the development of education and a cost-effective, efficient and flexible way to meet the needs of students in acquiring new knowledge.

1. Assigning the objective

The professional qualification of shipping industry workers must comply with the International Maritime Organization (IMO) requirements irrespective of the country they receive their education in. The trade market imposes the requirements to the level of future specialists competency the system of education must provide. Under the given conditions competency-based approach is regarded to be an efficient mechanism that makes it possible to bring into compliance the professional training and the requirements of the employees.

Maritime academy graduates over a period of many years have proved to be competitive specialists. This fact enables their employment in high-rank international shipping companies.

In the context of IMO requirements, information technology as a technological science and a subject form a holistic information space of knowledge aimed at solving any tasks related to professional competencies.

The main objective of the course "Information technologies" which is taught during the first year of education in maritime academy is the provision of the digital literacy of future shipping industry personnel.

The content of the course is designed in such a way that together with the specific course competencies the cadets are provided with the opportunities of the system of universal professionally-oriented competencies formation.

Specially designed and selected tasks are characterized by the applicable complex nature aimed at giving future seafarers a feel for the methods and ways of professional tasks and problems solving by means of digital technologies usage and specifically the use of cloud services.

For example, the content of the academic material of the course "Information technologies" includes the following task types:

(i) tasks that contain a big amount of information given in the form of tables, diagrams, graphs, schemes, etc.;
(ii) tasks aimed at mathematical (information) model constructions and the solution algorithm realization by means of MS Excel;
(iii) complex tasks with the big amount of tasks on different topics and formats that require different solution algorithms, forms of answer fixation (the selection of the appropriate software, the application of the received skills and the use of competencies in real conditions);
(iv) tasks aimed at the technological processes optimization, taking into consideration of all possible situations and ways of decision taking.

The academic material of the course contains predominantly not a formalized but contextual problem description so that the stage of formalization can be done by a student himself. The process of mathematical or informational task model construction is the most difficult but at the same time the most important one for own actual experience in practical problem solving acquisition.

The construction of the model of the technological process presupposes the introduction of the accurate ways of data collection, clear and precise description of the processing procedures, determination of output indexes and the analysis of the received results With the help of the functional potential of the spreadsheets (using MS Excel, Google Sheets as example) and successfully designed frameworks it becomes possible not only to receive the problem solutions automatically but also to carry out experiments and analyze data for the final decision taking.

The subject of the research is the newest conceptual approaches to the usage of computer-based modeling in the process of practical problems solving for the formation of professionally-oriented competencies.

The paper objective is the methodology development for the technological process modeling on the basis of the spreadsheet MS Excel and by means of cloud services use in particular.

2. Recent research and publications on the topic analysis

The issues of computer modeling introduction in the course of Information Technologies studies are discussed and worked out by such foreign and Ukrainian specialists as R. Maier, A. Bochkin, S. Rakov, S. Semerikov [1]. The fundamental principles of numerical methods of mathematical problems solving are published in scientific and educational works by such famous authors as S. Chapra, R. Canale [2], I. Teplytskyi, S. Lytvynova [3], Z. Seidametova [4] and others. The modern applications of numerical methods are closely connected with the use of information technologies that is why a lot of scientists view spreadsheets as computer-based environment for the modeling process.

The problem of cloud services use in the course of information subjects teaching has been studied by M. Popel, M. Shishkina [5], A. Kiv [6], A. Striuk [7]. The stages of the individual work organization by means of cloud services provided by Google, Microsoft companies are described in the works by V. Franchuk, O. Voronkin, T. Vakaliuk [8]. The problems of the competency-based approach implementation into the system of education and professional training of future seafarers have been discussed and researched in the works by many teachers of Kherson State Maritime Academy [9].

Besides, the scientific information sources have been analyzed that contain such technical information related to the ship handling as the determination of ship position, the rules of shipboard devices data checking, the methods of fuel supply for a specific voyage calculations taking into consideration the sufficient provision even in case of stormy weather. For example, the ways of voyage fuel expenses optimization by means of its economy and decrease of voyage time are described and grounded in the works by P. Buklys, A. Ershov [10]. The issues of fuel consumption rationing system creation are revealed in the scientific works by Yu. Platov, Yu. Lysnyak, V. Tveritin [11].

The description of methodology for shipboard supplies calculations and their rationing can be found in the scientific works by V. Vinnykov [12]. Foreign scientists such as L. Goldsworthy, R. Elsner [13] have also paid great attention towards the matters of optimal use of ship resources. For example, R. Shennon, V. Shostak argue that the efficient solution of many technical tasks and problems becomes possible due to the imitational modeling implementation.

The thorough analysis of the above mentioned research works and papers allows for the conclusion that the use of computer-based modeling as the tool for practical problems solving is still among the problems of immediate interest.

The stated ideas have been taken into consideration when developing the syllabus for the course “Information technologies” (IT). The main objective of the course is not only to cultivate cadets skills of qualified calculations performance required in the course of professional activity but rather to form and develop the competencies which are considered to be the basic ones in the lists of professional requirements stipulated by International crewing agencies.

3. Main problem solving

Mathematical modeling involves the creation of the analytical description of a technological or economical process, for example, in the form of algebraic equations, differential equations or logical conditions systems. To study the mathematical model it is possible to use analytical and numerical methods. Recently the numerical methods are carried out by the means of computer-based programs among which the spreadsheet is considered to be one of the most useful.

When teaching the course Information Technologies the computational and graphical potential of MS Excel and Google Sheets were used for computer modeling.

One of the main topics which are included into the syllabus of the course is the use of Excel in the professional activity of marine officers. While studying this topic, students are taught both standardized and unified aspects of basic training such as the ability to structure the input data, the ability to create the algorithms for calculation performance or data base according to the given conditions, the ability to use built-in resources as well as the basic aspects of the professional software operation.

The specific position among all cloud services belongs to the Google Workspace package. This is a free of charge package for educational establishments that includes all capabilities of the professional package. Google Workspace is the Web-application based on the cloud computing which provides both teachers and students of higher educational establishments with the instruments required for the effective communication and cooperation.

The main advantages of Google Workspace usage for the educational purposes from the point of view of a user are:

- minimum requirements to the hardware (the only compulsory conditions – the availability of the Internet access);
- cloud technologies do not demand the expenses on the buying and maintenance of the specialized software (the access to the applications can be received via the Web-browser window);
- Google Workspace support all operational systems and client software programs which are usually used by students and educational establishments;
- the work with the documents is done via any mobile device which supports web browsing;
- all Google Workspace for Education instruments are free of charge.

Let‘s analyze in detail as an example one of the tasks studied during the course Information Technologies and which has multiple purposes.

Practical problem statement: to determine the amount of fuel stores required for a period of independent sailing of a ship.

Explanation to the problem statement. The qualified shipboard engineer must be able to provide trouble-free and reliable operation of all shipboard systems and installations, their adequate exploitation, on schedule high quality repairs and maintenance as well as to be able to use rationally information technologies for the purposes of tasks performance related to the operation of ship propulsion systems.

Besides, a professional seafarer must have the skills and knowledge which will allow for the technological problem statement structuring, creation of the algorithms for its solving in one of the standard forms in such away it is clear to all personnel working in the area. This requirement is especially crucial for seafarers as when the crew changes, the newcomers need to be able to become quickly involved into the process and provide for the non-stop work performance.

To provide for the safe operation and exploitation of a ship it is necessary to calculate correctly the stability, the buoyancy, the trimming and other vital seagoing characteristics. When determining these parameters it is required to take into consideration the correct ship loading and the cargo plan which should be in all respects correct and in compliance with all the rules and requirements.

Before preparing a cargo plan it is necessary first of all to pay attention to the storage of all shipboard supplies among which fuel is considered in the first place.

The fuel stores calculations is the complex task which must take into account many factors, for example:

(i) deadweight and cargo carrying capacity of a ship;
(ii) the distance a ship can make without entering a port for supplies replenishing;
(iii) voyage duration and laytime;
(iv) ship sailing speed;
(v) the type and power of ship propulsion system;

(vi) technical condition of the engine;
(vii) fuel ration en route and at anchor;
(viii) type and sort of fuel;
(ix) engine capacity factor;
(x) season of the year (summer or winter);
(xi) geographical coordinates of the sailing area;
(xii) fuel price in different ports.

It is necessary here to describe some of the above mentioned factors in more details as they will be used in the future calculations and their impact on problem solving must be taken into account.

The distance a ship can make without entering a port is in direct ratio to the amount of the supplies received on board and the supplies ration consumption during the voyage. The biggest percent of all supplies is for the fuel. If one increases the amount of fuel supply received on board it can greatly reduce the residual free space of a ship used for the cargo which, in turn, can result in voyage unprofitability.

The technical condition of all ship propulsion, the type and specification of the main engine, ship sailing speed influence the consumption of the fuel. For example, the amount of fuel that is used is in almost cubic dependence on the ship sailing speed. When calculating the general amount of fuel need for the voyage it is recommended to provide for the availability of different fuel specifications.

When determining the amount of fuel supply it is necessary to take into consideration the fuel ration en route as well as the fuel ration at anchor in which case the consumption depends on the operating principle of loading and discharging procedures. If the loading procedure is done by means of shore cargo handling facilities, then the fuel ration is approximately twice lower than in the case when loading procedure is done by the means of shipboard cargo handling gear.

After the calculation of the amount of fuel stores with the account for all the above mentioned factors it is necessary to add to the received number approximately 15-20% more to establish the supply needed for the case of stormy weather.

In some shipping companies there are some norms of the amount of fuel supply for the case of stormy weather established but usually they do not exceed 20 of the fuel amount calculated for a voyage. For the small-power ship engines the percentage of the fuel supply for the case of stormy weather is smaller, for example:

(i) in summer for all areas of the World Ocean 3-5% but there are some exceptions (10% for the Atlantic area to the North from 30° N, for the Bengal Bay 15%, in the Arabian Sea 30%);
(ii) in winter period the percentage of the supply for the case of stormy weather depends on the sea where a ship is operating: 20% - for the Baltic and the Japan Seas, 10% - for the Black Sea, for the Mediterranean Sea to the North from the 40° this amount is 20% [12].

There are different methods of ship supplies calculations. For example, to calculate the amount of fuel needed for the voyage with the account for the amount required for the case of stormy weather it is possible to use the formula:

$$P_{fuel} = 1,1 q_t t_x, \tag{1}$$

where
P_{fuel} - is the amount of fuel supply in tons,
q_t - is the fuel consumption in tons per day;

t_x - sailing time in days;

The amount of lubricant supply is usually 5% from the calculated fuel supply.

The results of the calculation of different types of shipboard supplies for the voyage for the sake of convenience of their analysis are given in the table format that allows for the optimal and correct loading plan creation.

The final stage of the loading plan actions – is the calculation of the gravity center coordinates for all types of ship supplies, cargo and ballast. When the loading procedure is over and the trimming is done the center of gravity for a whole ship is calculated.

In a specialized maritime literature there is a description of the calculations normalization stage [12].

Taking into consideration the fact that the amount of fuel supply immediately depends on the voyage duration it is necessary to determine the sailing time first with the account of possible delays:

$$t_V = \frac{l}{24V} + t_{Dl} \tag{2}$$

where

l - is the distance between the ports;

$24V$ - daily ship speed;

t_{Dl} - time of delay en route.

It is also necessary to take into consideration the time of ship′s berthing time in ports which in turn depends greatly on the amount of the cargo to be loaded or discharged:

$$t_B = (\frac{Q}{M} + t_{aux}) + (\frac{Q}{M^1}) + t_{aux}) \tag{3}$$

where

Q - is the amount of cargo;

M, M^1 - cargo handling labour standards in a port (loading and discharging respectively).

In that case the formula to be used for the amount of fuel stores calculation will look like following:

$$G_T = g_{cv} t_v k_{gale} + g_{cb} t_b \tag{4}$$

where

g_{cv}, g_{cb} - are the daily fuel consumption amounts en route and at anchor;

k_{gale} - the quotient of the supply needed for the case of stormy weather.

As we can see the number of factors to be considered is quite numerous and they all have to be taken into account to provide for the optimal and safe ship sailing. Non-optimal use of fuel can result in unprofitability of the whole voyage. The knowledge of the engineering data from official documentation and the rules of ship propulsion systems exploitation is one of the key professional responsibilities of shipboard engineers.

Of course, for the modern shipboard engines there are standard parameters of fuel consumption but, as it is stated in many scientific sources, they do not take into consideration many of the described factors that influence the consumption.

The general fuel consumption may be divided into the following components:

(i) Nameplate data of engine – this is the amount of fuel consumption which must be expected on board when the hull of the ship, her propellers are in satisfactory conditions and her engines and boilers have correct settings, etc.

(ii) Additional fuel consumption which is related to the deterioration of the condition of the hull (foulness), with the deterioration of the condition of the propellers, main and auxiliary engines.

(iii) The so called nonoperational fuel consumption which depends on weather conditions, on sailing area, on the time of the engine operation.

In real ship sailing conditions there is a constant need to specify and determine more exactly the nameplate data of fuel consumption and thus Chief Engineers are often faced with a problem of adequate fuel consumption standards creation. In the case of insufficient amount of fuel taken on board the crew will have to operate the main engine in inadmissible working modes which can result in premature wear and tear and thus will increase the risk of emergency situations.

All of the above mentioned allows for the conclusion that the task of fuel consumption calculation is the complex problem which requires thorough analysis of engineering data from official documentation as well as the consideration of specific individual factors of ship sailing.

The most visually compelling ways of presenting the factors which influence the general fuel consumption and the fuel consumption rate is by means of the following schemes, shown in figures 1, 2.

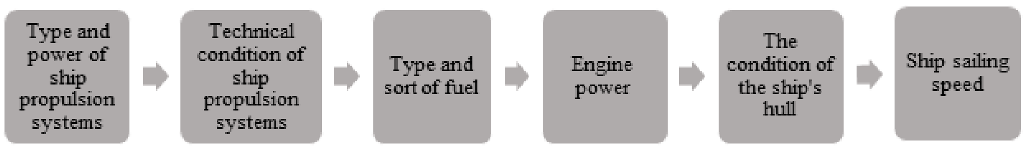

Figure 1. Factors that influence the general fuel consumption on ships.

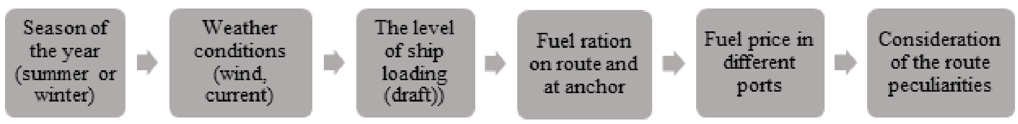

Figure 2. Factors that influence the fuel consumption rate on ships.

The mathematical description of the bunkering procedure optimization can be represented by the following correlations:

$$\sum_{i=1}^{N} Z_i V_i \rightarrow min \tag{5}$$

$$\sum_{i=1}^{N} V_i \geq V_R \tag{6}$$

$$F = max(\frac{Z_i V_i}{T_i})), i = 1...N \tag{7}$$

where

Z_i - is the fuel price in port i with the account taken of the delivery price to a ship;

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V_i - is the amount of the fuel being loaded on a ship;
V_R - is the minimum fuel capacity for the voyage;
T_i - is the time of bunkering operation,;
$\frac{Z_i V_i}{T_i}$ - is the speed of bunkering operation in port i;
F -is the bunkering speed ranking.

It is clear that on big vessels of major crewing companies there is professional software installed which includes among others the program unit for voyage fuel stores calculations. Unfortunately, the same cannot be said about the entire vessel operating nowadays. During the period of education in maritime academy a cadet must go deeply into the technology of the procedures he/she will have to participate in when being on board. This research enables deeper understanding of the voyage fuel amount calculations algorithm with the account taken of all necessary parameters, the full calculations plan development, output data structuring, the determination of the succession of calculations done, the received results assessment.

For that purpose in order to explain the cadets the problem solving algorithm it was decided to create the framework for the spreadsheets which contains all necessary basic information. In this part of the research it is proved, first of all, that the spreadsheet is the universal application which can be installed on all shipboard computers or can be used as on-line service. This fact allows for the creation and support of the unique databases both professional and copyrighted programs. Second of all, it has been demonstrated by the means of the example how to analyze the technical task and to optimize the further work.

	A	B	C	D	E	F	G	H	I	J	K	L
1			Navigation zone of the vessel								Fuel type	
2			Oceans	Seas					Direction		Full name	Short name
3	Season			1	2	3	4	5	to North	N	Heavy Fuel Oil	HFO
4	Summer-Autumn	1	Atlantic	Hudson Bay	Barents Sea	Red Sea	Bering Sea	Amundsen Sea	to South	S	Low Sulfur Fuel Oil	LSFO
5	Winter-Spring	2	Arctic	Baffin Bay	Kara Sea	Gulf of Aden	Gulf of Alaska	Weddell Sea	to East	E	Marine Diesel Oil	MDO
6		3	Indian	Gulf of St. Lawrence	Beaufort Sea	Persian Gulf	Sea of Cortez (Gulf of California)	Ross Sea	to West	W	Marine Gas Oil	MGO
7		4	Pacific	Caribbean Sea	Greenland Sea	Gulf of Oman	Sea of Okhotsk	Great Australian Bight				
8		5	Southern	Gulf of Mexico	Chukchi Sea	Arabian Sea	Sea of Japan	Gulf St. Vincent				
9				Sargasso Sea	Laptev Sea	Bay of Bengal	Seto Inland Sea	Spencer Gulf				
10				North Sea	East Siberian Sea	Gulf of Thailand	East China Sea	None				
11				Baltic Sea	None	Java Sea	South China Sea					
12				Gulf of Bothnia		Timor Sea	Beibu Gulf					
13				Irish Sea		None	Sulu Sea					
14				Celtic Sea			Celebes Sea					

Figure 3. The fragment of the database according to the sailing area, sailing direction and fuel type.

Electronic spreadsheet framework consists of the following sheets: Title page, Fuel stock, Lists, Diesel engine (figure 3). In the real life conditions the consideration of all the parameters the influence fuel consumption the suggested framework of the spreadsheet may be added by unlimited number of sheets – databases. The information from the additional sheets will be used for the calculations on the main sheet Fuel stock which contains basic information on the ship particulars such as the information about the manufacturer (Producer) of the main and auxiliary shipboard engines, the time of boiler operation (Boiler runtime), time of mooring operations (Mooring time), the duration of navigation (Navigation duration) and the speed of a vessel (Ship′s speed).

All other indices of the Fuel stock sheet such as the engine power (Power of engine), specific fuel consumption (Specific fuel consumption) are computational ones. To calculate those indices, it is necessary to use the databases located on the Lists and Diesel engine sheets respectively.

The Lists database contains the full information on the sailing area choice (Navigation zone of the vessel), sailing direction (Direction), type of fuel (Fuel type). The Diesel engine database includes all technical information on the diesel engines (Technical data of marine diesel engines).

The next stage in accordance to the formulated objective of the research is the calculation making itself. At this stage the cadets′ attention is drawn to the integrated functions of the spreadsheets which are not so often used when making routine calculations. For the sake of the convenience of the input data interface it is possible to use the links to technical data sheets Lists and Diesel engine, to create drop-down data lists, to use related lists, etc. (figure 4).

The use of Excel spreadsheets capabilities enables the automation of the calculation procedure and developed efficient mathematical model takes into consideration all the impact factors that can influence the calculations.

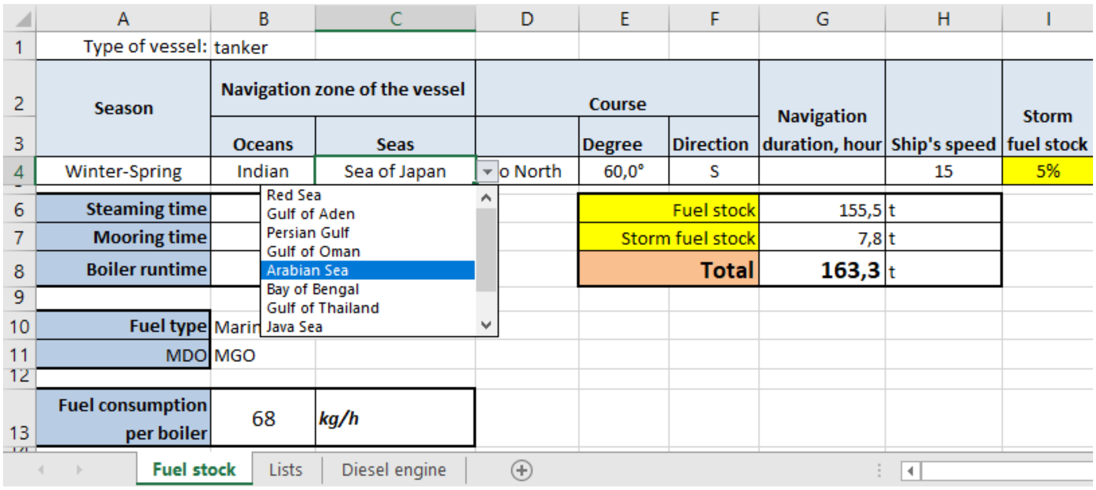

Figure 4. Data-entry form.

The algorithms for the amount of fuel stores calculation in the suggested task was developed in such a way that if we use successively such integrated spreadsheet functions as IF, INDEX, MATCH we will be able to review all the above mentioned parameters and receive the final answer (figure 5).

This information will be of great use for the cadets when studying other professionally-oriented subjects because they will be able to use the ready framework for the calculations under the condition they understand its operating principle or they will be even able to create their own frameworks in compliance with the conditions of a problem.

It is obvious that for the completion of this task a cadet must demonstrate excellent skills in the procedure of mathematical calculations performance by formulas, which is also considered to be one of the important elements of the integrated approach to education. For example, to calculate the amount of the voyage fuel stores B_T the following formula is used:

$$B_T = ((g_e N_e + g_e' N_e')t_V + g_e'' N_e'' t_b + B_k t_k) \cdot 0,001 \tag{8}$$

where

t_v, t_b- are the times spent en route and at anchor;

N_e, $N_e^{'}$, $N_e^{''}$- are the power of the main and auxiliary engines;

$g_e, g_e^{'}, g_e^{''}$ - are the specific fuel consumptions for the main and auxiliary engines;

B_k - is the fuel consumption for the boiler.

As we can see the research encompasses the whole range of elements which can provide for the integrated professional training of maritime academy cadets before they start their first shipboard practice and in the course of their further professional activity.

	A	B	C	D	E	F	G	H	I
1	Type of vessel:	tanker							
2	**Season**	**Navigation zone of the vessel**		**Course**			**Navigation duration, hour**	**Ship's speed**	**Storm fuel stock**
3		**Oceans**	**Seas**		**Degree**	**Direction**			
4	Winter-Spring	Indian	Sea of Japan	to North	60,0°	S		15	5%
6	**Steaming time**	120	***h***			Fuel stock	155,5	t	
7	**Mooring time**	15	***h***			Storm fuel stock	7,8	t	
8	**Boiler runtime**	10	***h***			Total	163,3	t	
9									
10	**Fuel type**	Marine Gas Oil							
11	MDO	MGO							
13	**Fuel consumption per boiler**	68	***kg/h***						
15	**Main ship engine**								
16	**Producer**	MITSUBISI							
17	**Engine**	VVZC (ДН15/20)							
18	**Power of engine**	ıe'!G4:G159;МАНТ(B17;'Diesel e		***kW***					
19	**Specific fuel consumption**	0,256		***kg/(kW*h)***					

Figure 5. Data-entry form.

4. Research results

Before the suggested methodology was introduced into practical process of tasks solving by cadets the authors of the developed electronic package made the teachers of professional subjects get familiarized with its content. During the process of familiarization the teachers were suggested a questionnaire to complete with the purpose to determine the practicability of the suggested package. In the questionnaire the teachers were asked to assess the comprehensiveness of the calculations, consideration of all factors that influence the amount of loaded fuel stores for the voyage, the convenience of the framework use, and the advantages of the suggested methodology in comparison with the usual ways of calculation performance.

To prove the adequacy of the model developed the real calculations were subject to the expert appraisal. In compliance with the works by Yu. Prokhorov, V. Frolov, H. Kravtsov [14] the algorithm for carrying out the expertise was developed. The authors of the research [15] have used the algorithm developed several times in previous research and it showed positive results. The group of experts who are qualified professional in maritime engineering have studied the functions of the suggested computer-based model and assessed its occupational potential.

The expert appraisal is aimed at determination of the compliance of the considered factors that influence the amount of fuel stores needed for the case of stormy weather to the real conditions, effectiveness and convenience of the suggested methodology of electronic spreadsheets usage while practical problem solving as illustrated by means of the example of voyage fuel supplies calculation, the experience cadets may gain in mathematical models design and their practical realization by means of spreadsheet.

The expert commission consisted of 12 people, who were asked to answer 16 questions after getting acquainted with the work of the author's computer model, i.e. the experts assigned a rank number to each parameter depending on its degree of significance.

Examination of the effectiveness of the method of computer modeling of the technological process should take into account the program-technological, cognitive, effective, reliable, psychological-pedagogical and other features.

An indicator of the quality and reliability of the model was a numerical parameter, using a five-point Likert system.

For an example we will give the table of parameterization of indicators of quality of model, where you an see 5 questions from 16 (table 1).

After collecting feedback from experts through a survey, a summary matrix of ranks was compiled (table 2).

The expert appraisal method is used to receive quantitative assessment of the qualitative characteristics by means of Likert scale. Each expert after having familiarized with the computer model answers the questions from the questionnaire independently of each other. Such procedure allows for the objective analysis of the problem and enables the development of its possible solutions. The data assessment during the expert appraisal was done in several stages:

(i) Weight coefficients of quality ranking or the construction of the table of generalized objects sequencing based on the averaging of their assessment.
(ii) Parameterization of the quality indices.
(iii) The conduct of the quality expert appraisal.
(iv) The research of the adequacy level of the obtained expert appraisal results.

Table 1. Questionnaire fragment, quality parameters and their weighting coefficients.

	Name of quality	Qualitative parameters	Weighting coefficient
1	Feasibility of using methods of mathematical (computer) modeling for calculation of storm and voyage stock of fuel	High Average Low	5 3 1
2	Efficiency of computer-assisted processing of results	Quality Above average Average Below average Low-quality	5 4 3 2 1
3	Adequacy of built model to the real process	Yes Partly No	5 3 0
4	The degree of use of the resource in relation to the maximum possible	Hight Average Low	5 3 0
5	Purpose of educational material for the relevant audience	Yes Partly No	5 3 0

Checking the correctness of the compilation of the matrix is the calculation of the checksum (for each row of the matrix):

$$\sum X_{ij} = \frac{(1+n)n}{2} = \frac{(1+16)16}{2} = 136 \tag{9}$$

The sums of the rows of the matrix are equal to each other and equal to the checksum, which means that the matrix is composed correctly.

The expert appraisal of the method effectiveness may be considered reliable only under the condition that the experts$'$ opinions comply with one another though the experts usually disagree. This can be identified by means of the concordance method. The concordance coefficient is usually calculated according to the formula:

$$W = \frac{12S}{m^2(n^3 - n)} \tag{10}$$

where

m - is the number of experts;
n - is the number of the questions in the questionnaire;
S - is the cumulative sum.

Table 2. Questionnaire fragment, quality parameters and their weighting coefficients.

Expert	Types of criteria									
	1	2	3	4	5	6	...	15	16	
1	3	8	13	4	7	2	...	15	1	135
2	4	10	11	6	8	2	...	16	1	136
3	3	10	12	7	8	2	...	16	1	136
4	4	7	10	6	8	2	...	15	1	136
5	2	10	14	9	8	3	...	16	1	136
6	3	9	10	8	7	2	...	16	1	136
7	2	12	11	8	10	5	...	15	1	136
8	2	11	14	7	9	4	...	16	1	136
9	2	11	14	4	8	9	...	15	1	136
10	2	5	13	8	7	3	...	15	1	136
11	2	11	12	6	10	5	...	16	1	136
12	2	9	11	7	8	3	...	16	1	136
$\triangle_i$	-71	11	43	-22	-4	-60	...	87	-90	0
S_i	5041	121	1849	484	16	3600	...	7569	8100	42836

In this research we have received the value of the concordance coefficient equal to $W = 0,876$. Since the coefficient of concordance varies from 0 to 1 (1 - the opinions of experts completely coincide), it can be concluded that there is a high degree of agreement among the opinions of experts.

To determine the significance of the concordance coefficient it is necessary to know the frequency array for the different values of the expert's number m and the objects number n. To assess the value of the concordance coefficient the Pearson's chi-squared test was calculated by means of the following formula:

$$\chi_w^2 = \frac{12S}{m * n(n+1)} \tag{11}$$

The calculated criterion χ^2 was compared to the table-value for the number of degrees of freedom $k = n - 1$ and at a stated level of significance $\alpha = 0,01$. The value of the received criterion χ^2 equaled 157,5 when the table-value was 30,58. Since the calculated value of the criterion χ^2 is greater than the tabular one, the concordance coefficient is not random, and therefore the results obtained make sense and can be used in further research. As the calculated χ^2 exceeded the table-value, it gave the grounds to state that the concordance coefficient is not a random variable, and therefore the results obtained make sense and can be used in further research.

5. Conclusions

Competency-based approach in education is intended not only for some amount of knowledge acquisition in the course of the set of subjects mastering in accordance with the curriculum. Every subject of the curriculum is viewed as an integral component of the academic process aimed at goal-oriented deliberate professional training of a specialist in a specific area. When developing the course content it is crucial to consider its connection with the set of professionally-oriented subjects. This task required the thorough analysis of A European Reference Framework for key competencies for lifelong learning. As the result of such analytical research teaching staff of maritime academy was able to update all academic disciplines content with the regard of competency-based approach implementation. In particular this is true about the course "Information technologies" which by its very nature presupposes the continuous updating in compliance with the current trends.

The consultations with the lead professionals of the graduate departments and cooperation with the part time learning students who have impressive sea-going experience and occupy high-level ranks enabled the development of the syllabus of the discipline "Information technologies" for the professional training of seafarers that takes into consideration both basic and professionally-oriented components.

The content of the discipline "Information technologies" includes the tasks closely related to the professional sphere of cadets operation and connected to the formalization, mathematical model construction and the use of computer technologies for the further research. Such tasks usually have complex character, are professionally-oriented, involve big amount of calculations to be done and require the implementation of the systematic approach when constructing the models or developing the calculation algorithms. In the course of digital technologies use cadets practice their skills of computer models construction, of the received results assessment that allows for their being aware of the whole new level of the acquired competencies.

In shipping industry there are many problems nowadays and their solution will provide for the industry effectiveness promotion.

The effective calculation of fuel supplies and the control of fuel consumption enable shipowners to implement goal-oriented measures as for the fuel saving that will result in economical profitability of the company.

The main objective of the research is to test the hypothesis as for the practicability of including the methodology of computer-based models construction and the use for the purposes of their realization of Microsoft Excel and Google Sheets into the course of academic discipline "Information technologies". The attempt was done by means of the example of the task for fuel supplies calculation.

Google Workspace tools are supported by different devices and thus are considered to be generally accessible and universal digital technology.

The article reveals the problem of professional training of specialists able to adapt easily and fast to the changing conditions and requirements of today in the context of information society globalization, who can use the latest achievements in the sphere of digital cloud technologies.

The approbation results of the suggested methodology proved that such approach provides for the maximum involvement of cadets into the learning process, provokes the motivation to study, to analyze the problem and find appropriate solutions.

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Practice of applying functional approach to the design of digital learning aids

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Practice of applying functional approach to the design of digital learning aids

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Abstract. In accordance with its aim, the paper highlights practical aspects and experience of the functional approach applying to the development of contemporary digital learning aids in the progress of project-driven activity of the pre-service IT specialists at their holistic vocational training. Theoretical framework of the work is made by holistic educational paradigm and functional approach to digital learning aids development. The specific examples of such an experience of the functional approach applying to the design of digital learning aids within project-based activity of the pre-service IT-specialists at their holistic vocational training: project activity on the design of (1) English digital tutorial for schoolchildren and (2) e-guide on the cryptography fundamentals for university students, are depicted in details. The analysis of such an activity is provided from the standpoint of the benefits of holistic and functional approaches. The prospects of following up research are covered.

1. Introduction

Discussing the importance of the current research, we would like to focus on some essential and mutually linked factors. On the one hand, necessity of the digital learning aids of new generation which is increased by the urgent needs of contemporary education at all of its level, connected with the current rapid shift to a blended and distant learning. The design of nowadays digital aids should be provided on the base of the progressive approaches which are relevant to the realization of prospective educational paradigms.

On the other hand, the process of preparing of pre-service specialists for life and successful work in contemporary volatile world is a complicated problem that currently needs for modification on the new level. The situation with the process of vocational training in different branches is exaggerated by the unexpected circumstances caused by the global pandemic and urgency of development new forms of teaching and learning. Thus, it is essential to create the upgraded model of the specialists' preperation based on new paradigms.

One of the options seems be the holistic educational paradigm, which is pointed out in a set of normative documents: National Strategy for the Development of Education in Ukraine for 2012-2021, the Law of Ukraine "On the Concept of National Education information programs", the Law of Ukraine "On Education" [1], the Concept of the New Ukrainian School [2], Education for Sustainable Development Goals: Learning Objectives etc. According to the studies on the problems of holistic education, it is discussed as a paradigm that supplies educators with a complex of principles that can be implemented in practice in different ways [3–5]. The core concept of this pedagogical paradigm is the holistic progress of the intire students' personality both at the mental and emotional levels [4]. It is also underlined in the scientific peapers that such a holistic progress should rest on the tight links between real-life tasks and trainee's personal experience. At the same time, the evidence of educational practice demonstrates that fruitful ideas of the holistic paradigm are taken and implemented in quite a limited way. As a result, the great deal of the essential paradigm facilities (like provision of integrity at the levels of the educational content, aids and forms of its application) are not realized in proper way.

Based on the speculations above, at the elaboration of the upgraded model of the vocational preperation, we tend to implement holistic outlook in the complex of different directions: to build the content of educational, to find out appropriate means of its representation and learning, and to provide potential specialists with professional practice. This concept is specified in the performing and application of (1) generalization and concentration of the said educational content resting on the integrative outlook of the curriculum subjects structuring; (2) multi-code rendering of the learning content focused on the reviving of trainees' cognitive processes; (3) native combining of the students'educational experiences with innovative technologies applications to the solution of real-life problems, which can be reached through project-based learning. It is relevant to emphasize that the said things cause and complement each other at the same time. This enables the holistic idea to obtain comprehensive realizing and deeper implementation into educational reality.

It is also important to mind that the realization of the main principles of the holistic theory demands proper system of the learning aids which are able to provide the cohesive development of the trainees' personality. This fact causes development of digital aids basing on the functional approach as the most advanced approach to their design.

In these lines, special attention should be paid to the training of IT specialists of various directions (including potential IT teachers) as for design, creation and applying of innovative didactic aids built on the basis of analysis of their functions, which enables to implement holistic paradigm to learning various disciplines at different levels of education. Therefore, one of the essential integral parts of the upgraded model of IT-specialists'vocational training rested on the holistic educational paradigm is the students' project-oriented activity on the development of digital learning aids [5, 6].

The aim of the paper is to highlight practical aspects and experience of the functional approach applying to the design of contemporary digital learning aids in the progress of project-based activity of the pre-service IT specialists at their holistic vocational training.

2. Theoretical framework

As a theoretical background, there were applied the complex of theoretical, modelling and empirical techniques. In the context of the said model of the potential IT specialists' training created on the holistic paradigm, their mastering of the development of innovative aids is provided both in the progress of learning of the complex of curriculum subjects (of common and prifessional training) and through the project-driven activity.

The theoretical framework of the research in the field of development of digital learning aids is made by the holistic educational paradigm (covered above) and functional approach to the design of digital learning aids.

The task of determination of didactic functions of tutorials and general functional outlook as for their design have got the focus in the works of researchers and practitioners (such as L. Bilousiva, V. Beilinson, L. Gryzun, D. Zuev, V. Kraevskyi, I. Lerner and many others [6–8]). The functional outlook rests on the analysis of the didactic functions of the learning aids and the ways of their realization by the aid. Such an approach to design of learning aids allows to determine the functional charge of their structural components and the relations between the fulfillment of their certain functions [7–11]. These concepts are getting increasingly essential in the lines of digital tutorials creation along with increasing their role in contemporary education.

The problem of didactic functions analysis has always been quiet complicated and ambiguous. There are a lot of views on their essence and classification. Basing on the learning of number of sources which represent great variety of the functions, we could distinguish certain groups of them that seem to be relevant exactly for the digital aids. In particular, *the first group* includes functions which promote studying motivation; *the second group* contains pure didactic functions that provide efficient representation of the learning content and its successful digestion; *the third group* includes functions of optimization of educational process in the lines of adaptation to the thrainee's learning needs; *the fourth group* is made of so-called meta-functions that encourage trainee's progress and increase their general educational potential which creates a basis for the further successful learning beyond the knowledge domain covered by this exact digital aid. It is important to emphasize that these groups of functions have general character. Depending on the target audience of the digital aid (schoolchildren or students), the type of academic discipline for which the aid is developed, some other factors, the accents and priorities of these groups of functions may be different.

However, anyway, the functional analysis for exact digital learning aid provides specific ways for developing the structure of the aid that should be consequently used as a theoretical fundamental for the process of its projecting. This process comprises establishing the structure of the learning guide which pins up the relations between its components, and determines the mechanism of these relations realization. In addition, this process should base on the comprehensive learning of the aid as an object of the projecting and design. Therefore, it is important to point out that a contemporary digital learning aid has been transformed into the entire tutoring environment that is able to overlay the facilities of the complex of typical learning aids. It became possible thanks to the using advanced technologies in the process of its design.

Besides determining the structure of a digital aid and clarification of the load of each its structural component, the functional approach contributes to the formulation of specific requirements to the aid and to the features of its design. This makes the process of the aid development practically driven, which is really essential for the students' project-oriented activity, as it gives the students clear understanding of the aims of their work, appreciating of its practical importance, increasing their motivation to design high quality aid which meets the requirements, clearly formulated basing on the functional analysis.

The presented theoretical framework may be seen as a base for the functional approach applying to the design of contemporary digital learning aids during the project-based activity of potential IT specialists at their holistic vocational training.

3. Results and discussion

The practical sides and evidence of the said activity are shown below on the examples of the creation of different digital learning aids provided by the students of different specialties within their project-oriented activity in the progress of their holistic training.

In particular, we would like to represent English digital tutorial which was created by the potential teachers of Computer Science and English in the progress of their project-based activity, provided with their preliminary learning of the set of common academic disciplines (English, Pedagogy, Programming, Computer graphics etc.) and professionally-oriented ones (Computer systems of English learning, E-pedagogy, Design of learning aids).

On the initial stage of the project the didactic functions of the digital tutorial were specified and its structure was outlined, according to the challenges of English learning at school. The project participants defined core requirements to the tutorial, revealed its functional facilities and determined its structure. Thus, it was concluded that in order to ensure the performing of the core functions, the English digital tutorial for 6th grade pupils must provide the set of facilities that are covered below with the reference to the groups of didactic functions (see Theoretical framework).

Firstly, the tutorial has to supply qualitative visualization of learning content and provide enough interactivity with a pupil. It will ensure high-level realization of developing, informational, transformational functions (the second group), functions of feedback and friendly correction (the first group), and the function of control (the third group). It must also garantee that the earning of linguistic competence of the pupils is intensified by the complex implication of the majority of information perception organs, which can ensure the efficient implementation of developing and transformational functions.

In addition, the learning aid has to give opportunity the trainees to work out their different speech skills, which may guarantee realization of consolidation and systematic functions (the second group). The tutorial must provide a reliable feedback with other pupils and a teacher to obtain assistant, consultations, estimation etc. (the second group). It should also realize the cognitive activity management comprising game activity for implementation of developing function and self-learning one (the fourth group).

Finally, the tutorial must to be smoothly integrated with differnet electronic resources, which ensures its coordinative and integrative facilities (the third group of didactic functions).

Based on the above functions and relying on research [6–8, 11, 12], the project participnats could create the structure of the digital tutorial which is able to implement efficiently its didactic facilities. Therefore, the students came to the conclusion that the teaching aid must be built as a complex of integrate parts presented below.

For high level visualization of the educational content, the tutorial should comprise a library of multimedia illustrations which supplies text, images, video, and audio information in integrated way.

In order to facilitate shaping of pupils' language competence through the complex using of many sense organs, the learning aid makes available an interactive video library with didactic provision. On purpose of developing of a variety of skills, the tutorial contains a bank of interactive exercises with an immediate delivery of the results of their fullfillment.

To manage learning activity, the aid provides a special component which includes also various game elements. There is also an appropriate component of the tutorial that holds communication with the teacher and other pupils.

In order to automate the processes of the content retrieval and integration with other e-resources, the aid is supplied with a technological ingredient that ensures its online uploading and the facility of its integration with differnet sources.

Determined didactic functions and structure of the digital tutorial made the basis of its development for the students who participated in the project.

Therefore, at the subsequent stages of the project, the said digital English tutorial for the 6th year pupils was built within Ourboox platform whose embedded facilities were enhanced by the students with some coded supplements.

It is essential to point out that the developed tutorial does not demand installation as it is an online multimedia aid (MultiEnglish). It comprises core themes learnt in the 6th grade at studying English: My family, Shopping, Food, Traveling, Sport, Ukraine, and others (see figure 1).

Every theme is presented in the sections (Let's focus on. . .) that aim at shaping and progress of core language skills: reading, vocabulary, grammar, speaking, listening, and writing (see figure 2). They provide necessary teaching materials, tasks, various exercises, quizzes etc. The demo version of the learning aid which is available on the Internet assumes current modifications of the tasks when it is necessary.

Figure 1. Content of the multimedia tutorial MultiEnglish.

Figure 2. Selected sections of the multimedia tutorial MultiEnglish.

In the progress of the tutorial development according to its didactic facilities and structure, embedded opporunities of the Ourboox environment were significantly enriched by the sudents with the help of HTML programming.

Intoducing programming instructions allowed to supply the aid with interactive elements of other services, which are unavailable within the standard Ourboox toolkit. In such a way, interactive exercises, posters, video-clips, games, static and dynamic illustrations, links to differnet services, such as Quizlet, YouTube, LearningApps, Google-forms, Jigsaw Planet, Vizia, Gettyimages, ThingLink, ESL Game Plus and others) were integrated into the developed learning aid (see figure 3).

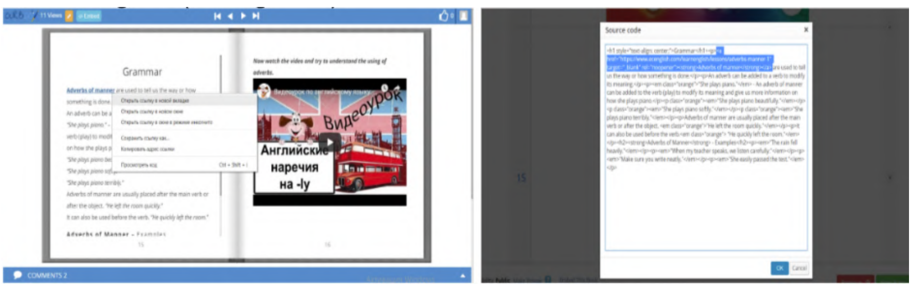

Figure 3. An example of an interactive elements of MultiEnglish embedded with programming.

The media content of the tutorial was created with the help of modification the HTML code of the aid's pages. In particular, the participants of the project were able to combine text, images, and video with the certain hyperlinks. In addition, with the help of programming, it was enhanced Ourboox´s facilities of text formatting: there were prepared instructions in HTML with CSS elements to align text correctly and to build lists. The students also realized integration of interactive didactic provision into the aid, which enables a trainee to watch the video with pauses at the certain places and do interactive exercises to the video story. In such a way, due to introducing of coded elements, the MultiEnglish tutorial became didactically powerful to realize all the didactic functions determined by the students at the first (theoretical) step of the project.

Final stage of the project was devoted to the analysis of the designed learning aid as for revealing and estimation of its didactic facilities.

Analyzing these features of the MultiEnglish tutorial which was created by the potential Informatics and English teachers based on a functional outlook in the progress of their project-dreven activity, it is relevant to underline the following.

The learning aid ensures high-level visualization of the learning content and enables interactive dialogue with the trainee. The rich library of multimedia images as a component of the tutorial represents the relevant elements of the content and maintain immidiate feedback. The library comprises both static and dynamic illustrations of differnet kinds including interactive posters which enable effective boosting trainee's vocabulary, its checking and working out (see figure 4).

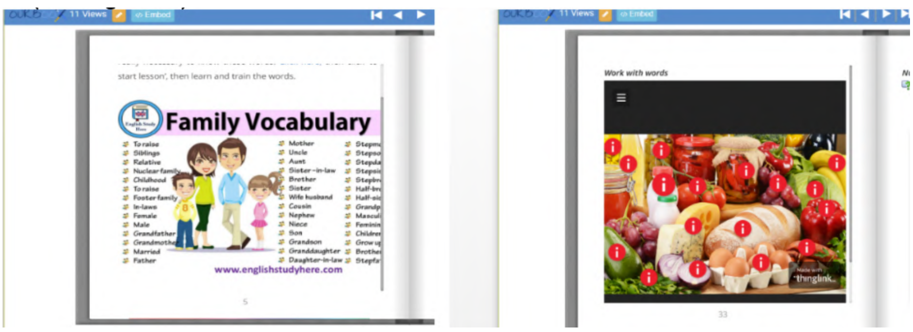

Figure 4. Episodes of work with the library of multimedia images.

The said facility garantees efficient implementation of transformational, informational, and developing didactic functions of the tutorial, and also the functions of self-control, feedback, and correction. In addition, the developed learning aid raises the effectiveness of shaping of language skills via involvement of the pupils' multi-senses activities into their learning practice. In particular, the tutorial enables trainees' work with interactive digital stories for which it has been prepared relevant didactic provision. Therefore, during watching the stories trainees are provided with the assignments developing their listening skills, boosting their vocabulary, stimulating the conscious using of grammar rules (see figure 5).

The developed MultiEnglish tutorial also allows to record trainee's speech aimed at developing their speaking and communication habits (see figure 6), which provides realization of the transformational and developing functions.

The developed digital aid encourages working out of differnet skills, which provides the facility of its using as a simulator. The vast library of interactive tasks offers pupils a variety of exercises of different learning types: matching, puzzle solving, word search, audio and video tasks, interactive texts etc. Thus, the anchoring and systematic functions are performed. Episodes of work upon the exercises of differnet kinds are given in (figure 7-figure 9).

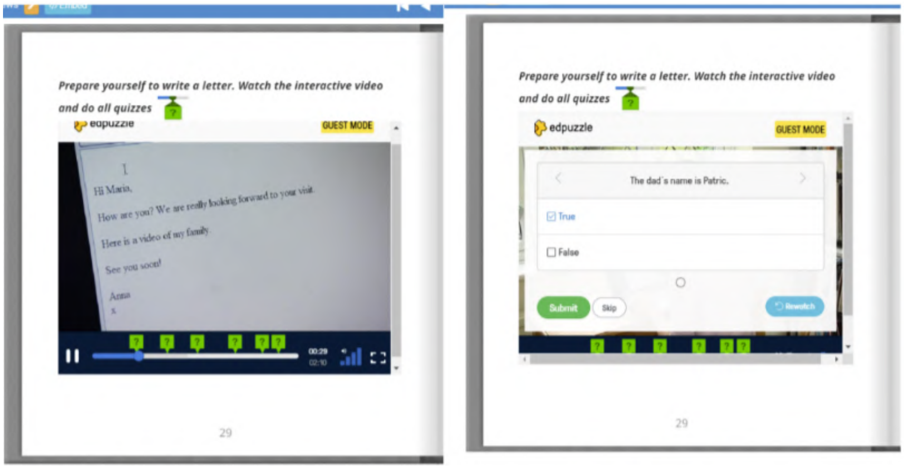

Figure 5. Work with interactive digital video-story "My Family".

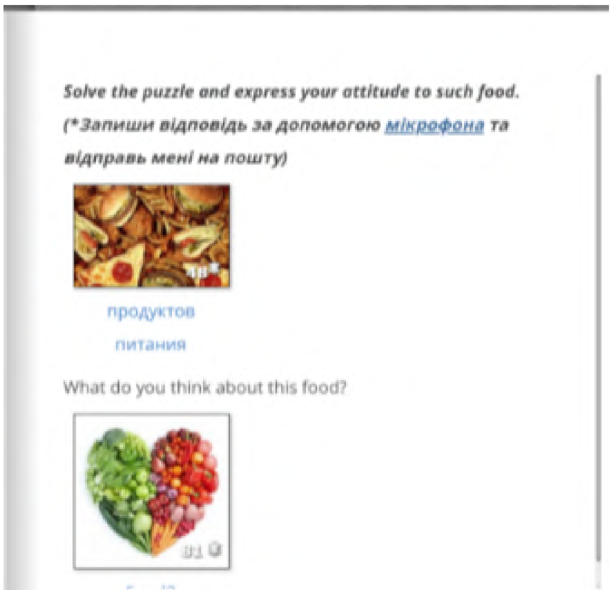

Figure 6. A situation of a pupil's voice recording during learning one of the themes.

As it was said above, the facilities of the developed aid also provide the organization of various cognitive activities. Therfore, a pupil has an opportunity to study at their individual pace, under the teacher's guidance or independently. In addition, all of the tasks can be done by trainees as many times as they need, to reach best results. For raising motivation for studying, the tutorial offers trainees game-based activities, such as quests, quizzes, cognitive grammar trips, crosswords and others (see figure 10). These tutorial facilities provide realization of the developing, consolidation, and systematic didactic functions (from the first, second and third groups).

The tutorial allows technologically to be uploaded to other sites and integrated smoothly with other electronic resources (see figure 11), which promotes the implementation of integrating and coordinating functions. It is also essential that the learning aid functions correctly with all browsers (Google Chrome, Opera, Microsoft Edge, Mozila Firefox, Internet Explorer).

In addition, the developed tutorial provides the facility which helps pupils to interact with

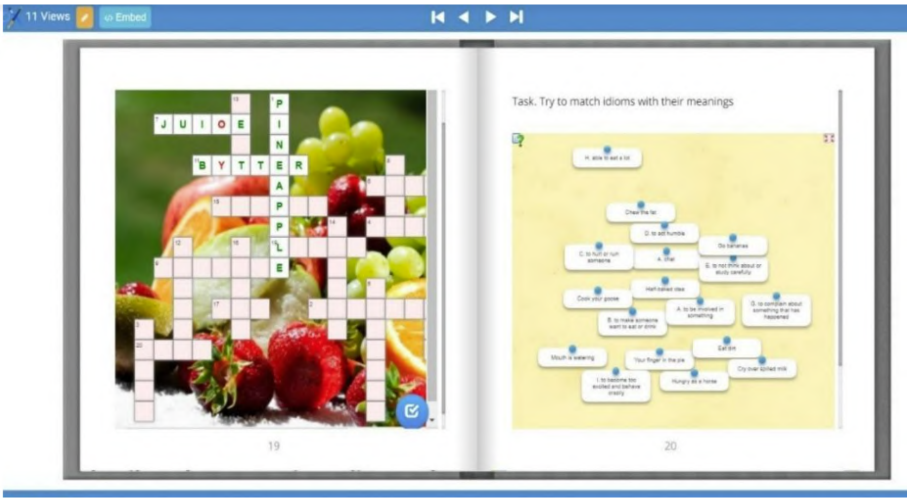

Figure 7. Episodes of work upon interactive crossword puzzles and exercise on matching.

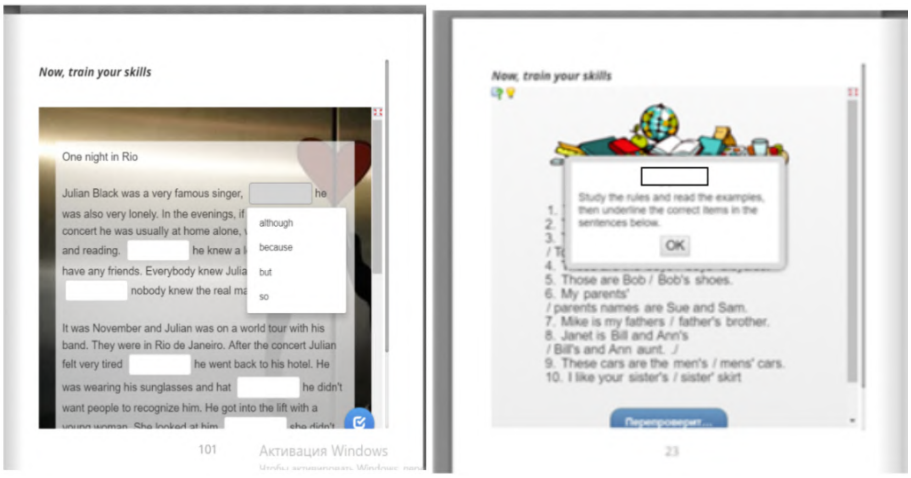

Figure 8. Episode of proceeding an interactive text.

their teacher. For example, comments element of the aid can be used to ask questions while doing an exercise, send a speech record to a teacher, or ask for help from the peers. Therefore, the didactic feedback function is implemented.

Thus, the analysis of the developed multimedia tutorial (done by the students at the final stage of the project) testifies that the tutorial which was developed basing of the functional approach is innovative one, as it provides a trainee with the integral cognitive environment for activity-centred learning. It can be characterized as a platform for pupils' free cognitive activity and for raising their motivation to learning. As a result, it promotes cohesive progress of both the students (project participants) and their potential pupils.

Diffent example of functional approach applying to the creation of innovative digital learning aids is the development of the e-guide on the cryptography fundamentals provided by pre-service IT specialists (unlike the first e-tutorial realized within vocational training of pre-service teachers of Computer Science and English), but also within their project-oriented activity in the process of their holistic training. Including this example, we also aimed to demonstrate main features of the approach realization on the samples of e-guides for completely different

Figure 9. Fragment of work with the video content.

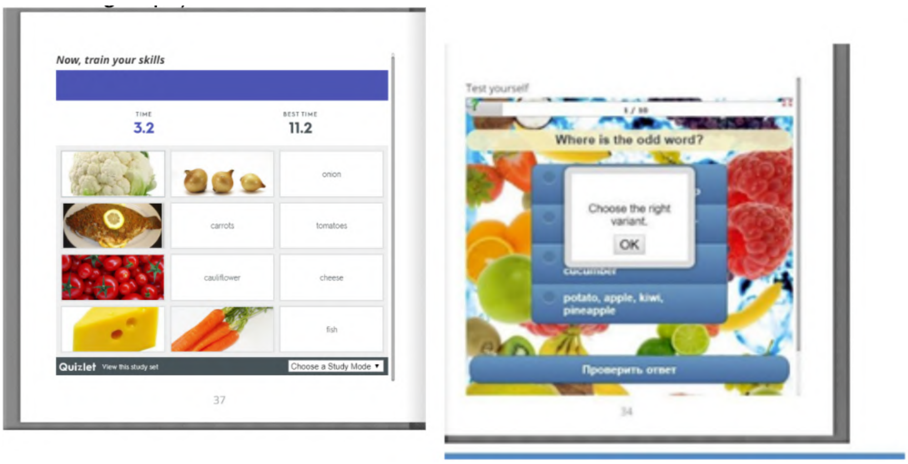

Figure 10. Episodes of the various kinds of game activities.

target audience (schoolchildren and university students), knowledge domain, forms of potential students' activities etc.

At the first stage of the project activity, the didactic functions and structure of the e-guide were determined due to problems of the course "Information security", which is a basic one for lots of vocations.

In such a way, resting on the theoretical background on the functional approach (covered above), the students defined proper structural components of the learning aid. In particular, it was determined that the e-guide must contain the textual component organized in hypertext form which presents systematized and didactically processed learning material according to the syllabus of the academic discipline. Here the place of the cryptography fundamentals in the course was determined, and the necessity of coverage in the aid of encryption as one of the means of information protection was established. The learning material was selected and structured on the basis of a number of sources on the basics of cryptography and modern computer encryption systems [10, 13–15].

It was also determined that the textual component has to provide transition to non- textual structural components: Illustrative material and Apparatus of the acquisition arrangement.

Illustrative material should contain the static illustrations (technical charts, schemes, photos,

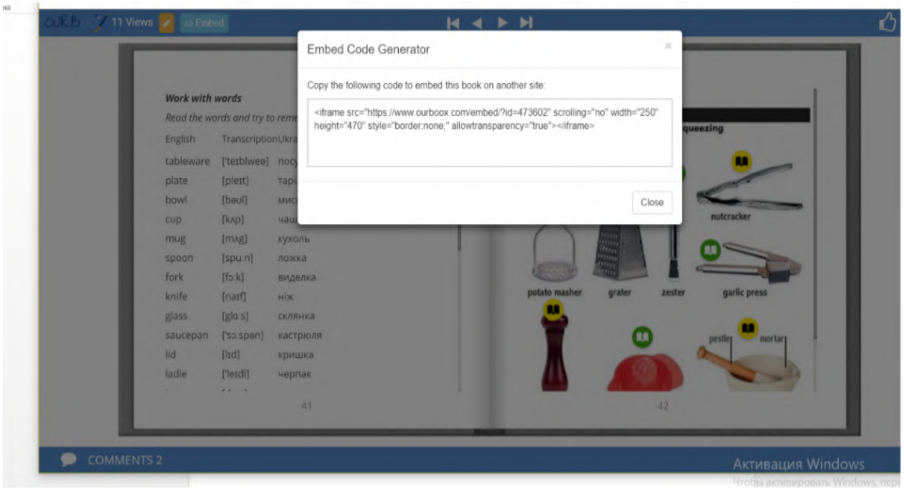

Figure 11. Embedding the tutorial into different site.

pictures etc.) and dynamic ones (animated or video illustrations that demonstrate different methods of information encrypting).

Apparatus of the acquisition arrangement should be represented by a library of learning tasks of different types and a system of self-checking. Among the learning tasks of the e- guide should be distinguished three basic types of the tasks: teaching, training and cognitive- search ones.

At the next stage of the students'project-oriented activity, the e-guide whose functions and structure were specified at the previous stage was developed in the environment of MS Learning Content Development System using its tools and facilities. The developed learning aid covers the following topics on the basics of cryptography: "Basic concepts of information security", "Cryptology as a science", "Classical encryption algorithms", "Computer encryption systems".

As it was planned, the e-guide contains a textual component organized in the form of hypertext, which allows to find quickly necessary learning material on the course, navigate easily the topics and sections, work with illustrations and tasks, refer to external links for other information resources (see figure 12).

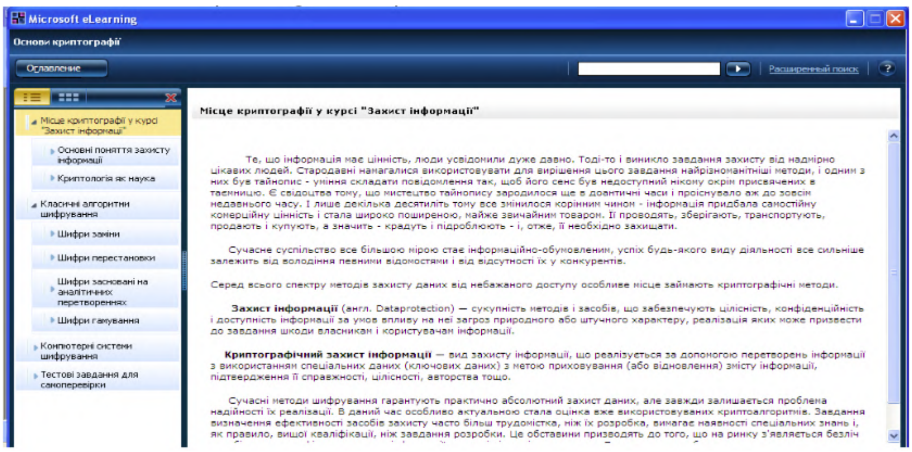

Figure 12. Episodes of work with the hypertextual component of the e-guide.

The textual component is supported by the Illustrative material component which provides a trainee with two types of illustrations. The first type includes static illustrations, such as generalized schemes of computer cryptosystems, the visualization of which facilitates the understanding of educational content (see figure 13), contributes to the transformational function and function of visual method use.

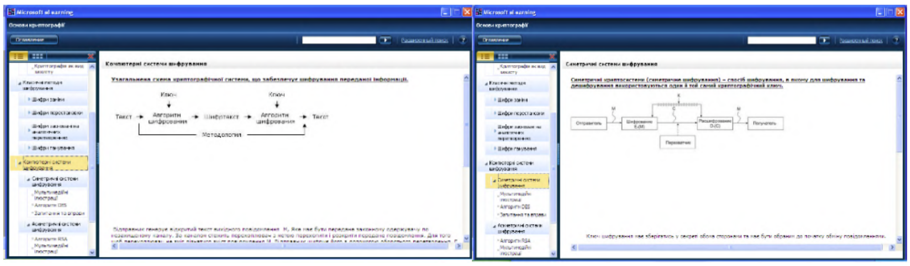

Figure 13. Work with static illustrations on the topics "Computer encryption systems".

The second type of illustrations are dynamic ones which demonstrate the process of data encrypting based on various encryption algorithms; processes that reproduce the sequence of actions in the operation of encryption algorithms, historical information, the essence of some abstract concepts, and so on. This component gives for potential trainees the opportunity to observe these processes, review them at different speeds and check the assimilation of the content, answering a number of questions to the reviewed dynamic illustrations offered by the e-guide.

Thus, the work provided by the e-guide with its hypertextual component supported by static and dynamic illustrations promotes implementation of informational, transformational and systematizing functions (the second group of functions depicted in the Theoretical framework above).

Apparatus of the acquisition arrangement of the e-guide, as it was planned, is represented by a library of learning tasks of different types that are focused on the mastering of theoretical content, and a system of self-checking.

The teaching tasks of the developed aid are ready-made programs (realized in different programming environments) that implement a certain encryption algorithm. The e-guide encourages a trainee to work with the program, to find out its purpose and functions, and to analyze the program code. In particular, the teaching tasks allow data encrypting and decrypting based on some classic encryption algorithms. The solution of the teaching task expects trainee's processing, according to a certain scheme proposed by the library of teaching tasks (or by the teacher). Trainees have the opportunity to run them, analyze the operation of algorithms and make conclusions by answering questions. In addition, it is possible to copy fragments of program code and use them to develop trainees'own programs (see figure 14-figure 15).

Training tasks include tasks similar to teaching ones, but students solve them independently, based on theoretical content and program implementation of teaching tasks. For example, working with the code of the learning task, a trainee masters the encryption of a certain algorithm, and then he is offered a training task to implement a decryption program by the same algorithm. Some of the training tasks are focused on working out the skills of using various encryption algorithms via the set of exercises. For example, for the topic "Replacement encryptions" and "Substitution encryptions", the e-guiede offers the set of exercises given at the (figure 16-figure 17).

Cognitive-search tasks presented by the Apparatus of the acquisition arrangement are aimed at applying knowledge at the creative level. Trainees are offered a number of tasks on each topic: tasks that require significantly transformed knowledge; tasks for independent application of different types of encryption algorithms; research tasks and comparative analysis of different

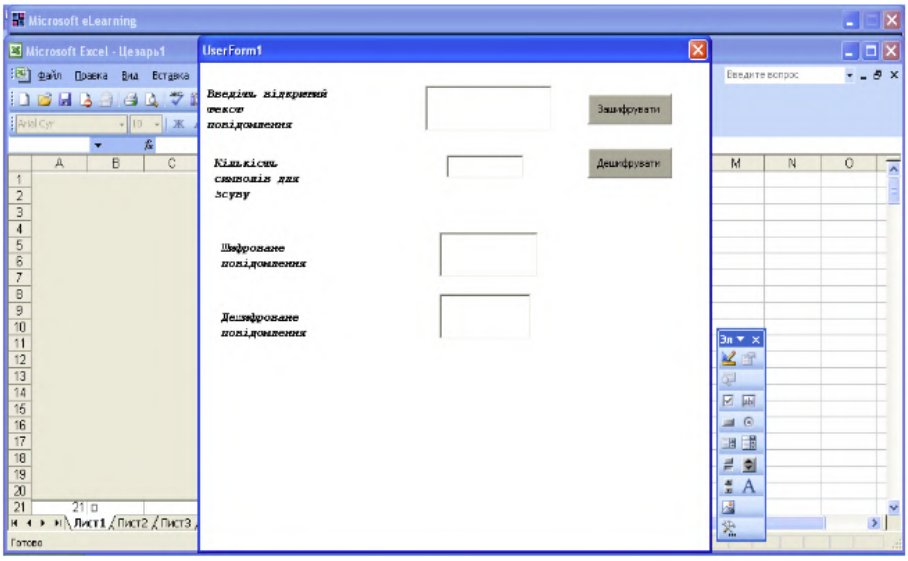

Figure 14. Teaching task for the implementation of the Caesar encryption algorithm.

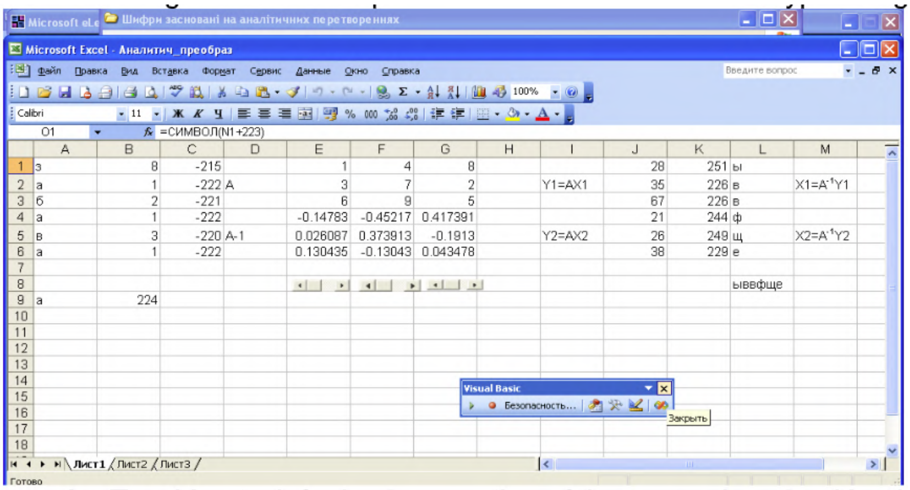

Figure 15. Teaching task for implementation of the encryption algorithm based on analytical transformations.

information encryption systems; complex tasks on the composition and those that involve gradual complication etc. Each task has instructions and answer, as well as the references to relevant theoretical material or to the teaching tasks of the manual.

Thus, the developed and filled library of the learning tasks allows to realize at a higher level the functions of consolidation (the second group of functions) and development (the fourth group of functions).

The self-checking system presented in the e-guide is realized with the help of Google Forms(see figure 18). The system includes a set of generalized test tasks to check the level of mastery of educational material. The form is connected to the Google spreadsheet and the answers of the respondents are automatically stored in it, which in turn allows the teacher to analyze the trainees'achievements. Thus, the implemented system of self-checking contributes to the implementation of such didactic functions as the functions of correction and contro (the third

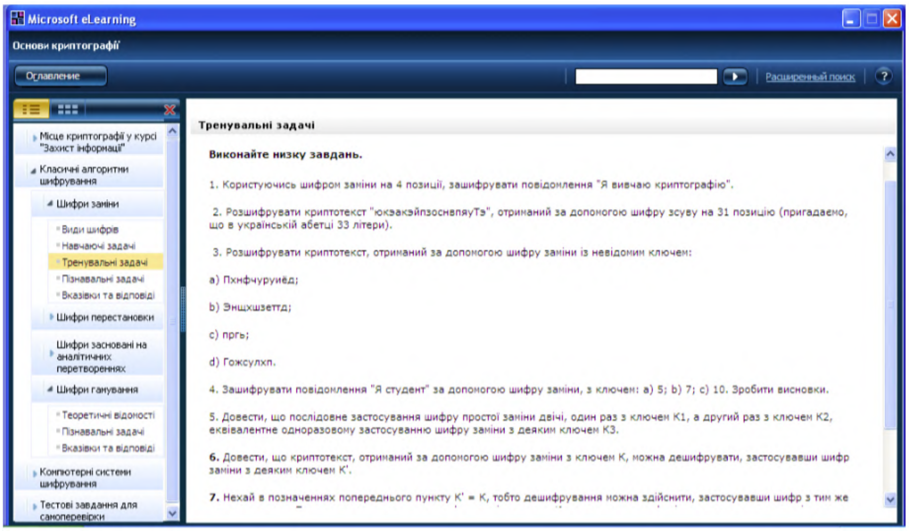

Figure 16. Fragment of work with training tasks on the topic “Replacement encryption”.

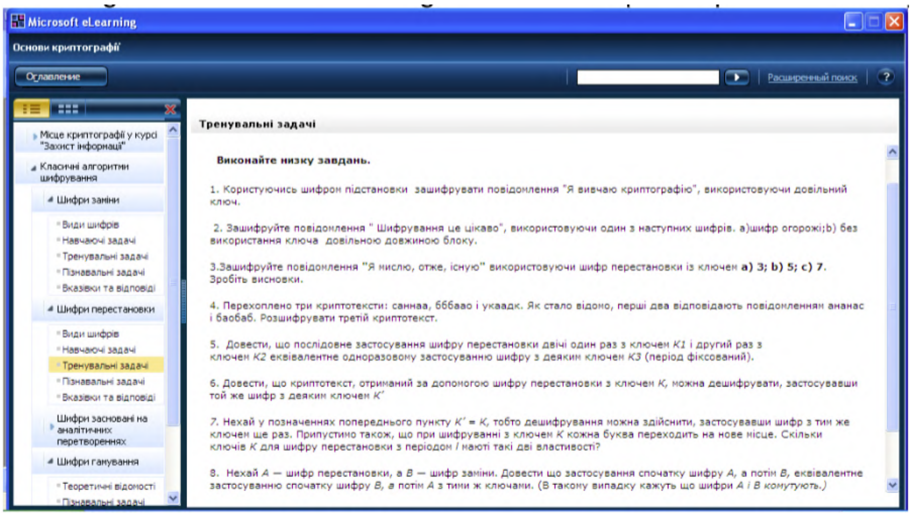

Figure 17. Fragment of work with training tasks on the topic “Substitution encryptions”.

group of functions), consolidation (the second group), and developing and educational function (the fourth group).

Thus, the digital learning aid, designed by the students based on the functional approach, makes a whole learning environment suitable for use in the educational process of IT specialists training within the course “Information Security” providing its holistic learning.

At the final stage of the students' project-oriented activity the developed e-guide was tested and elaborated. In addition, there were offered some methodical recommendations as for its using at the educational process of the university in its different forms.

Summing up the depicted experience and specific examples, we would emphasize the following. The functional approach which was applied by the students to the design of the digital learning aids demonstrated its great benefits as for the quality of the aids as the results of the students'project-oriented actvity. In particular, the functional approach enabled the students (1) to specify the doals of development; (2) to determine the aid's structure components, their

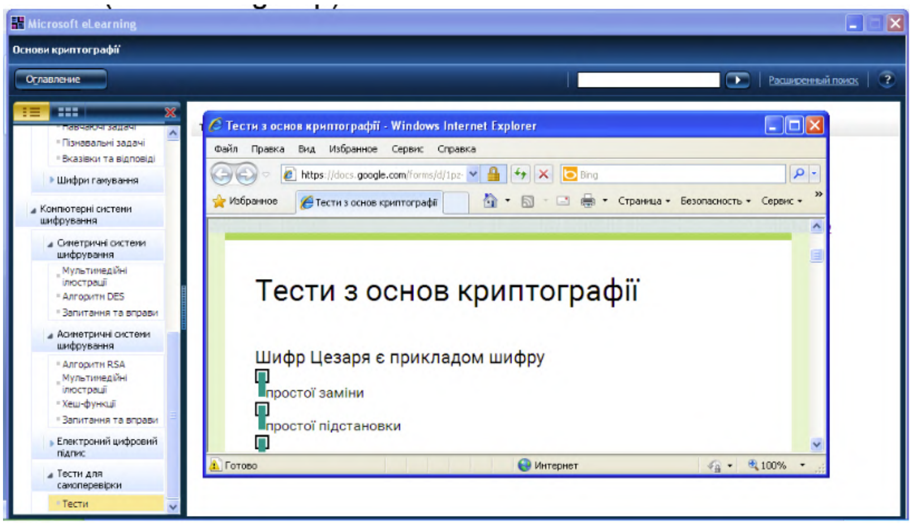

Figure 18. The fragment of work in self-checking system of the e-guide on the fundamentals of cryptography.

purposes, and their mutual connections; (3) to clarify the choice of the fulcrums for the purposes achievement; to control the process of the aid development; (4) to provide objective estimation of the results; (5) to promote the demand and practical application of the created digital learning aid. Here, it is important to point out that the result of the academic project-oriented activity had not only learning value, but also obtained essential practical application. Th elaborated digital learning aids were approved in the real educational processes at school and at university during various kinds of practices. The results of the work were also presented during the students conferences and workshops.

It is also worth underlying, that on condition of such an interdisciplinary preparation and project activity, pre-service IT specialists obtain meta-skills on the design of innovative digital learning aids. In the process of this kind of training, potential pre-service IT specialists obtain full understanding and capability for practical embodiment of core ideas of holistic educational approach via their personal experience of development of the learning aids. In addition, the application of the fuctional approach made students' project activity more practically-driven and motivational.

Thus, we could anticipate the positive impact of such professional training on the shaping of students' holistic system of their knowledge and skills. Elaboration of the methodology of its diagnosing may be a prospect of following up research.

4. Conclusions

In accordance with its goal, the paper covers practical aspects and experience of the functional approach applying to the development of contemporary digital learning aids in the process of project-based activity of the pre-service IT specialists at their holistic vocational training.

Theoretical background of the research includes holistic educational approach and functional basics of digital didactic aids development. The specific examples of such an experience of the functional approach applying to the design of digital learning aids within project-based activity of the pre-service specialists of different branches of their preparation at their holistic vocational training are depicted in details. In particular, there are examples of students' project activity on the design of (1) English multimedia tutorial for schoolchildren (done by the pre-service teachers of Computer Science and English) and (2) e-guide on the cryptography fundamentals for university students (done by the pre-service IT specialists).

The analysis of such an activity is provided from the standpoint of the benefits of holistic and functional approaches.

The prospects of further research are outlined. It is planned to investigate the influence of this kind of training on the forming of the students' holistic system of professional knowledge and skills. On this purpose, it is assumed to elaborate proper methodology of its diagnosing and estimation, which is a prospect of our following up research.

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About some aspects of the organization of students individual work at pedagogical universities in the process of teaching classical optimization methods

About some aspects of the organization of students individual work at pedagogical universities in the process of teaching classical optimization methods

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Abstract. Some aspects of teaching classical optimization methods to students of computer science specialties of pedagogical universities are described in the article. In Ukraine pedagogical universities the theory of optimization problems is most systematically considered in the course "Mathematical programming". The paper presents the approximate topics of this course, analyzes the relevant interdisciplinary links, presents the main stages of solving applied optimization problems. The peculiarities of organizing the individual work of students who study according to the dual education system by using the elements of "flipped" learning are considered in the article. New approaches in the educational process with the using of the modern information technologies, in particular Maple computer math system, is demonstrated.

1. Introduction

The methodical aspects of the organization of individual work of students during the study of mathematical programming with computer support are considered in the work. The using of modern information technologies not only eliminates the need to perform a significant number of routine computational operations for students, but, above all, contributes to a deeper understanding of the essence of various optimization methods. It is clear that formal algorithms for solving optimization problems, which are often quite simplified, are based on the classical results of mathematical analysis, linear algebra, analytical geometry, functional analysis, probability theory etc. Teaching students optimization methods leads to awareness of not only theoretical but, above all, the applied orientation of their mathematical education, the importance of knowledge from various fields of mathematics in their further professional activities. This attitude of students to classical mathematical postulates can be formed when teaching "Mathematical Programming", in particular, through the use of new information technologies, because with a very limited number of classes, a significant amount of time can be spent on formalizing the problem and analyzing appropriate optimization methods and received solutions.

Pedagogical specialties students mostly work as teachers in secondary schools, starting from the last year of bachelor's degree, not to mention master students. The insufficient number of teachers in Ukrainian schools, first of all the teachers of natural and exact sciences contributes to this also. Therefore, the main purpose of introducing a dual education system in a pedagogical university is to create conditions and opportunities for the most prepared and motivated students as well as effectively combine theoretical training at the university with practical implementation of their knowledge at school [1–3].

Students studying according to the dual education system and working in secondary education institutions learn respective disciplines according to individual plans and schedules.

Methods of teaching with the using of modern innovative forms are an urgent scientific and practical task today. The study of the state, prospects, and development of the modern innovative forms of learning in the educational process by using information technology is considered in the M. Zhaldak [4], V. Bykov [5], N. Morze [6], Yu. Tryus [7], O. Spirin [8] and many other scientific works [4,6,8–17].

Today in higher education institutions there is a gradual but steady transition of the learning process from the transfer knowledge to students to the management of their educational and cognitive activities, and formation skills and abilities of their individual work. Teachers-researchers S. Arkhangelsky [18], V. Buryak [19], B. Johansen [20], S. Zinoviev [21], P. Pidkasisty [22] and others engage with problems of organizing students individual work.

To effectively organize the students individual work during their studies students should develop, implement, and protect their individual or group projects to solve specific problems.

Another effective way of organizing students' individual work is through the use of digital technologies, in particular, the technology of "flipped" learning through various e-learning courses [23–29].

Unfortunately, it should be noted that the interest of modern young people in the classical theoretical teaching of mathematical disciplines has significantly decreased: most of students do not seek to master the complex mathematical results on their own and use, if its necessary, the Internet reference resources or the most simplified methodological developments. Therefore, to implement the relevant curriculum and to provide students with the basic theoretical knowledge, it is necessary to use new approaches in the educational process with modern information technology, in particular computer math systems, not only while performing the practical tasks, but also during teaching the basic theoretical mathematical positions, avoiding at the same time incorrect simplifications.

Some aspects of teaching classical optimization methods in the course of mathematical programming to students of computer science specialties with a "mathematics" specialization are presented in the article.This course is designed for master students who have mastered basic mathematical and computer science courses.

2. Statement of basic material

The subject of studying the course "Mathematical Programming" is the basic information about the problems of mathematical programming, classical optimization methods of functions of one and many variables, the basic formulations review, methods of researching and solving problems of linear, nonlinear, integer, discrete, stochastic, convex, dynamic programming as well as modern information systems and technologies that are used in researching and solving the specific applied problems of mathematical programming.

At the Pedagogical University the following topics of the course "Mathematical Programming" are offered:

- The Subject of mathematical programming. The Review of historical information.
- Ancient extreme problems.
- Classification of mathematical programming problems.
- Linear programming tasks.

- Duality in linear programming problems.
- Integer and discrete programming problems.
- Nonlinear programming problems.
- Problems of stochastic programming.

Note that this course structure is not classical. However, in the study of these topics in the proposed sequence the motivational factors of learning clearly show. Consideration of classical historical optimization problems emotionally "paints" the learning process, which together leads to a higher level of student achievement. The organic combination of practical problems and theoretical methods of their solution contributes to the establishment of close interdisciplinary links, improves the quality of education of students not only in this discipline, but also in related mathematical disciplines.

During teaching this course it is important to pay attention to the generalization of the material, its practical significance, the implementation of interdisciplinary links between mathematical and computer science disciplines because, acquiring the "master" educational level, students need to rethink, develop, and use previously acquired knowledge and skills both in theoretical aspects and in their practical application.

During teaching the mathematical programming the basic concepts of the corresponding types of problems of mathematical programming, their statement, formalization and construction of mathematical models are considered, optimality conditions which are necessary and sufficient conditions for the existence of functions of one and many variables extremum are investigated and analyzed, different types of problems are solved with the help of classical analytical and numerical optimization methods, a comprehensive analysis of optimal solutions is performed. At the same time much attention is paid to the appropriate using of computer math systems and specialized software environments for analyzing, researching, and solving mathematical programming problems [30–33].

As already mentioned, the main purpose of introducing a dual education system at a pedagogical university is to create conditions and opportunities for the most prepared and motivated students to effectively combine theoretical training at the university with the practical implementation of their knowledge at school [34–36]. The main advantage of dual education in the pedagogical field is that students dont remain unemployed after their studies and schools are equipped with qualified subject teachers, including computer science and mathematics.

Students studying according to the dual education system and working in secondary education institutions learn respective disciplines according to individual plans and schedules.

To effectively organize the students individual work during their mathematical programming studies they should develop, implement, and defend their individual or group projects to solve specific optimization problems in which it is necessary to provide:

- selection of the problem content component from a certain field of knowledge;
- problem formalization, construction and research of its mathematical model;
- selection of effective methods for solving the problem;
- development of an effective algorithm for solving the problem;
- selection of effective, pedagogically-balanced information technologies to solve the problem;
- finding problem solutions using various software environments and tools;
- comparison and analysis of the obtained results;
- using modern information technologies of training, in particular WEB 2.0, during projects preparation and defence.

Another effective way of organizing students' individual work is through the use of digital technologies, in particular, the technology of "flipped" learning through various e-learning courses.

The using of "flipped" learning technology in the educational process provides an opportunity to make the transition from learning aimed at mastering theoretical materials in the classroom, when the teacher is the main source of knowledge, to practice-oriented learning of students and their active involvement in the educational process. It also promotes students' individual learning at a convenient time and place, which is the purpose of using distance learning technologies and e-learning courses [23–29].

"Flipped" learning is the learning principle, according to which the main assimilation of knowledge by students takes place outside the classroom, and during classroom work students perform and defend laboratory and practical research, individual and group projects, consult with a teacher, etc. Bergmann J. and Sams A., the authors of the "flipped" learning concept recorded video lectures and posted the relevant videos on the Internet [23, 24]. By watching videos, students could gain basic knowledge before class. Of course, the method of self-study before the lesson is not limited by watching videos - it can be texts, lecture presentations, test tasks to control and self-control the level of acquired knowledge, laboratory work, individual project tasks and any other educational materials prepared and placed by a teacher, for example in the distance learning system MOODLE.

Here is the tasks example of the individual project "Setting, researching, solving and analysing nonlinear programming problems" during teaching the mathematical programming to students of computer science specialties with a "mathematics" specialization.

Task 1. Formalize, build mathematical models, solve the ancient extreme problems (Euclid, Tartaglia, Kepler, Steiner, Heron, Apollonius) [30] as nonlinear programming problems.

Task 2. Solve the selected nonlinear programming problems by Lagrange multiplier method.

Task 3. Solve the selected nonlinear programming problems by the classical method of finding the extremums of functions of one variable.

Task 4. Solve the selected nonlinear programming problems by the classical method of finding the extremums functions of many variables.

Task 5. Solve the selected nonlinear programming problems by approximate gradient methods of finding the extremums of functions of one variable.

Task 6. Solve the selected nonlinear programming problems using a genetic algorithm.

Task 7. Compare and analyze the results.

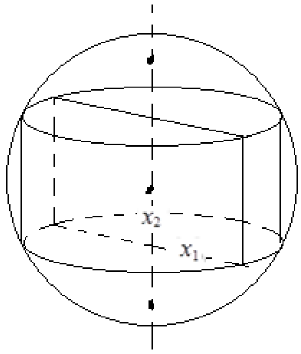
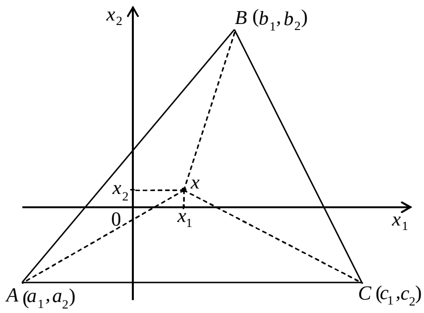
Directions. When analyzing the obtained results do the following:

- variant types of analysis such as parametric, multicriteria, conditional initial data, structural, etc.;
- get solutions on demand;
- analyze the overcoming solutions incompatibilities for the relevant tasks;
- analyze the overcoming of the objective function infinity for the relevant tasks;
- save the scripts of relevant solutions and prepare reports.

Further we demonstrate some elements of performing such tasks in the environment of Maple computer math system [31, 33] for Kepler (stereometric variant) and Steiner ancient extreme problems, presented in table 1, as conditional and unconditional optimization problems respectively.

Kepler found an analytical solution to this problem: $V_{max} = \frac{4\sqrt{3}r^3}{9}$. It was also found that the Kepler stereometric problem solution is a cylinder in which the ratio of the base diameter to the height is equal $\sqrt{2}$. Let's check it, carrying out the above task, for a sphere of the given radius $r = 2.5$. Numerical solution of the Kepler problem with the using the *extrema()* function is shown on the figure 1.

Table 1. Setting math problems.

	Setting problems	Geometric visualization	Mathematical models
Kepler problem	Fit the largest volume cylinder into a sphere of a given radius r.		Two-dimensional model: $f(x_1,x_2)=2\pi x_1^2 x_2 \to \max,$ $f(x_1,x_2)=x_1^2+x_2^2-r^2=0,$ where x_1 is the radius of the inscribed cylinder base, x_2 is half the cylinder height. One-dimensional model: $f(x_1,x_2)=2\pi x^2\sqrt{r^2-x^2}\to \max,$ $0\le x\le r.$
Steiner problem	In the triangle plane find a point sum of the distances from which to the triangle vertices is minimal.		$f(x)=\rho(x,A)+\rho(x,B)+$ $+\rho(x,C)\to \min,\ x\in R^2,$ where $\rho(x,A)$, $\rho(x,B)$, $\rho(x,C)$ are distances from the desired point to the known vertices of the triangle ABC.

Kepler stereometric problem

$r := 2.5;$

$$2.5$$

$extrema\left(2\cdot \mathrm{Pi}\cdot x1^2\cdot x2,\ \{x1^2+x2^2=6.25\},\ \{x1,x2\},'s2'\right);$

$$\{-37.78748673,\ 37.78748673\}$$

$s2;$

$$\{\{x1=-2.041241452,\ x2=-1.443375673\},\ \{x1=-2.041241452,\ x2=1.443375673\},\ \{x1=0.,\ x2=-2.500000000\},\ \{x1=0.,\ x2=2.500000000\},\ \{x1=2.041241452,\ x2=-1.443375673\},\ \{x1=2.041241452,\ x2=1.443375673\}\}$$

$\dfrac{2.041241452}{1.443375673};$

$$1.414213562$$

$evalf\left(\dfrac{4}{9}\cdot\sqrt{3}\cdot\pi\cdot r^3\right);$

$$37.78748677$$

Figure 1. Kepler stereometric problem.

The Answer. The largest volume 37.79 has the inscribed cylinder with the base radius 2.04 and the height $1.44 \cdot 2$, which coincides with the analytical solution of the problem with sufficient accuracy. Kepler problem solution by using a package *Optimization* is shown on the figure 2.

> **Kepler stereometric problem**

$with(Optimization);$

$[ImportMPS, Interactive, LPSolve, LSSolve, Maximize, Minimize, NLPSolve, QPSolve]$

$NLPSolve(2 \cdot \mathrm{Pi} \cdot x1^2 \cdot x2, \{x1^2 + x2^2 = 6.25\}, assume = nonnegative, maximize);$

$[37.7874867551481444, [x1 = 2.04124143617281, x2 = 1.44337569581893]]$

Figure 2. Kepler stereometric problem.

The results coincide with the above.

The analytical solution of Steiner's problem is the so-called Torricelli point, from which all the triangle sides are visible at an angle of 120 degrees. If a triangle has an angle not less than 120 degrees, then the Torricelli point is the vertex of this angle.

Numerical solution of the Steiner problem by using the *minimize()* function is shown on the figure 3.

Steiner problem

$a1 := -3.; a2 := -2.; b1 := 3.; b2 := 5.; c1 := 6.; c2 := -2.;$

$$-3.$$
$$-2.$$
$$3.$$
$$5.$$
$$6.$$
$$-2.$$

$f := (x1, x2) \rightarrow \mathrm{sqrt}((x1 - a1)^2 + (x2 - a2)^2) + \mathrm{sqrt}((x1 - b1)^2 + (x2 - b2)^2) + \mathrm{sqrt}((x1 - c1)^2 + (x2 - c2)^2);$

$$(x1, x2) \rightarrow \sqrt{(x1 - a1)^2 + (x2 - a2)^2} + \sqrt{(x1 - b1)^2 + (x2 - b2)^2} + \sqrt{(x1 - c1)^2 + (x2 - c2)^2}$$

$f(0, 0);$

$$15.76105849$$

$minimize(f(x1, x2), x1, x2, location);$

$$14.87007737, \{[\{x1 = 2.542963252, x2 = 0.4923292395\}, 14.87007737]\}$$

Figure 3. Steiner problem.

The Answer. A point $(2.54; 0.49)$ is found in the plane of the given triangle, the sum of the distances from which to the triangle vertices is minimal and equal to 14.87 with the accuracy to rounding errors.

There are a number of methods for solving conditional optimization problems that can be used to find the solutions of above problems effectively.

The Lagrange multiplier method, the main idea of which is to transform the conditional optimization problem into the unconditional optimization problem, is implemented in many optimization software packages.

$$L(x_j, \lambda_j) = f(x_j) - \sum_{i=1}^{m} \lambda_j V_i(x_j) \to \max,\ i = \overline{1, m},\ j = \overline{1, n},$$

where $L(x_j, \lambda_i)$ is a Lagrange function, λ_i is Lagrange coefficients; $f(x_j)$ is an objective function, $V(x_j)$ is constraint-equalities in the conditional optimization problem.

Further we demonstrate the Lagrange multiplier method application on the example of solving Kepler problem and compare the results.

We write the Lagrange function:

$$L(x_1, x_2, \lambda_1) = 2\pi x_1^2 x_2 - \lambda_1(x_1^2 + x_2^2 - r^2) \to \max .$$

Find the Lagrange function partial derivatives for its variables using the *diff()* function, obtain the system 3 nonlinear equations, and solve it using the *solve()* function (figure 4).

> Kepler stereometric problem

$r := 2.5;$

$$2.5$$

> $L := 2 \cdot \mathrm{Pi} \cdot x1^2 \cdot \mathrm{x2} - \mathrm{lamda} \cdot (x1^2 + x2^2 - r^2);$

$$L := 2\, Pi\, x1^2\, x2 - lamda\, (x1^2 + x2^2 - 6.25)$$

$eq1 := diff(L, x1) = 0;$

$$4\, Pi\, x1\, x2 - 2\, lamda\, x1 = 0$$

$eq2 := diff(L, x2) = 0;$

$$2\, Pi\, x1^2 - 2\, lamda\, x2 = 0$$

$eq3 := diff(L, lamda) = 0;$

$$-x1^2 - x2^2 + 6.25 = 0$$

$sist := (solve(\{eq1, eq2, eq3\}, \{x1, x2, lamda\}));$

$\{lamda = 2.886751346\, Pi, x1 = 2.041241452, x2 = 1.443375673\}, \{lamda = -2.886751346\, Pi, x1 = 2.041241452, x2 = -1.443375673\}, \{lamda = 2.886751346\, Pi, x1 = -2.041241452, x2 = 1.443375673\}, \{lamda = -2.886751346\, Pi, x1 = -2.041241452, x2 = -1.443375673\}, \{lamda = 0., x1 = 0., x2 = 2.500000000\}, \{lamda = 0., x1 = 0., x2 = -2.500000000\}$

Figure 4. Kepler stereometric problem.

From the obtained solutions we choose the one that satisfies the conditions $x_1 \geq 0$, $x_2 \geq 0$: $\lambda_1 = 2.89\pi$, $x_1 = 2.0412$, $x_2 = 1.4434$.

The results coincide with the above (see figures 1 and 2), taking into account the calculation errors.

The *Sensitivity Report*, obtained using MS Excel, according to which the Lagrange multiplier for this problem is equal to 9.9990662 is shown on figure 5, which coincides with the results given above (see figure 4).

Microsoft Excel 16.0 Sensitivity Report
Worksheet: [NonLinProgr.xlsx]Kepler's problem
Report Created: Fr. 11.06.21 12:12:26

Variable Cells

Cell	Name	Final Value	Reduced Gradient
A4	X1	2,0412015	0
B4	X2	1,4434328	0

Constraints

Cell	Name	Final Value	Lagrange Multiplier
B8	обмеж. X2	6,2500017	**9,0693557**

Figure 5. Kepler stereometric problem.

Further we demonstrate the solution of the above nonlinear programming optimization problems by classical methods of finding the extrema of functions of one and many variables.

To find the Kepler problem solution, whose formalization leads to finding the maximum of the function of one variable (see table 1), we use the general rule of finding solutions of one-dimensional optimization problems: we find all stationary points of the function $f(x)$, i.e. the equation roots $f'(x) = 0$ with are the necessary conditions for the function extremum, and then with the help of sufficient extremum conditions in terms of second-order derivative values in stationary points we determine which of the stationary points are points of local minimum or maximum (figure 6).

\> **Kepler stereometric problem**

$r1 := 2.5;$

$$2.5$$

$f1 := x \to 2 \cdot \mathrm{Pi} \cdot x^2 \cdot \mathrm{sqrt}\left(r1^2 - x^2\right);\; eq1 := diff(f1(x), x) = 0;$

$$x \to 2\,\pi\,x^2 \sqrt{r1^2 - x^2}$$

$$4\,\pi\,x\sqrt{6.25 - x^2} - \frac{2\,\pi\,x^3}{\sqrt{6.25 - x^2}} = 0$$

$r2 := solve(eq1, x);$

$$0.,\, 2.041241452,\, -2.041241452$$

$f22 := diff(f1(x), x\$2);$

$$4\,\pi\sqrt{6.25 - x^2} - \frac{10\,\pi\,x^2}{\sqrt{6.25 - x^2}} - \frac{2\,\pi\,x^4}{\left(6.25 - x^2\right)^{3/2}}$$

$eval(f22, x = 2.041241452);$

$$-34.64101608\,\pi$$

Figure 6. Kepler stereometric problem.

Since $f''(1.767766) = -34.6410\pi < 0$, the objective function reaches the maximum at this point. The results coincide with above solutions of this problem (see figures 1 and 2).

The solution of the Steiner problem by the classical method of finding the functions extremum of many variables (in our case - two variables) is shown in figure 7.

> **Steiner problem**

> $a1 := -3.;\ a2 := -2.;\ b1 := 3.;\ b2 := 5.;\ c1 := 6.;\ c2 := -2.;$

$$a1 := -3.$$
$$a2 := -2.$$
$$b1 := 3.$$
$$b2 := 5.$$
$$c1 := 6.$$
$$c2 := -2.$$

$f1 := \mathrm{sqrt}\left((a1-x1)^2+(a2-x2)^2\right)+\mathrm{sqrt}\left((b1-x1)^2+(b2-x2)^2\right)+\mathrm{sqrt}\left((c1-x1)^2+(c2-x2)^2\right);$

$$\sqrt{(-3.-x1)^2+(-2.-x2)^2}+\sqrt{(3.-x1)^2+(5.-x2)^2}+\sqrt{(6.-x1)^2+(-2.-x2)^2}$$

$eq1 := (diff(f1, x1)) = 0;$

$$\frac{1}{2}\frac{6.+2x1}{\sqrt{(-3.-x1)^2+(-2.-x2)^2}}+\frac{1}{2}\frac{-6.+2x1}{\sqrt{(3.-x1)^2+(5.-x2)^2}}+\frac{1}{2}\frac{-12.+2x1}{\sqrt{(6.-x1)^2+(-2.-x2)^2}}=0$$

$eq2 := (diff(f1, x2)) = 0;$

$$\frac{1}{2}\frac{4.+2x2}{\sqrt{(-3.-x1)^2+(-2.-x2)^2}}+\frac{1}{2}\frac{-10.+2x2}{\sqrt{(3.-x1)^2+(5.-x2)^2}}+\frac{1}{2}\frac{4.+2x2}{\sqrt{(6.-x1)^2+(-2.-x2)^2}}=0$$

$r1 := (fsolve(\{eq1, eq2\}, \{x1, x2\}));$

$$\{x1 = 2.542963252,\ x2 = 0.4923292395\}$$

$eq11 := (diff(f1, x1, x1));$

$$-\frac{1}{4}\frac{(6.+2x1)^2}{\left((-3.-x1)^2+(-2.-x2)^2\right)^{3/2}}+\frac{1}{\sqrt{(-3.-x1)^2+(-2.-x2)^2}}-\frac{1}{4}\frac{(-6.+2x1)^2}{\left((3.-x1)^2+(5.-x2)^2\right)^{3/2}}+\frac{1}{\sqrt{(3.-x1)^2+(5.-x2)^2}}-\frac{1}{4}\frac{(-12.+2x1)^2}{\left((6.-x1)^2+(-2.-x2)^2\right)^{3/2}}+\frac{1}{\sqrt{(6.-x1)^2+(-2.-x2)^2}}$$

$eq22 := (diff(f1, x2, x2));$

$$-\frac{1}{4}\frac{(4.+2x2)^2}{\left((-3.-x1)^2+(-2.-x2)^2\right)^{3/2}}+\frac{1}{\sqrt{(-3.-x1)^2+(-2.-x2)^2}}$$
$$-\frac{1}{4}\frac{(-10.+2x2)^2}{\left((3.-x1)^2+(5.-x2)^2\right)^{3/2}}+\frac{1}{\sqrt{(3.-x1)^2+(5.-x2)^2}}$$
$$-\frac{1}{4}\frac{(4.+2x2)^2}{\left((6.-x1)^2+(-2.-x2)^2\right)^{3/2}}+\frac{1}{\sqrt{(6.-x1)^2+(-2.-x2)^2}}$$

$eq12 := (diff(f1, x1, x2));$

$$-\frac{1}{4}\frac{(6.+2x1)(4.+2x2)}{\left((-3.-x1)^2+(-2.-x2)^2\right)^{3/2}}-\frac{1}{4}\frac{(-6.+2x1)(-10.+2x2)}{\left((3.-x1)^2+(5.-x2)^2\right)^{3/2}}$$
$$-\frac{1}{4}\frac{(-12.+2x1)(4.+2x2)}{\left((6.-x1)^2+(-2.-x2)^2\right)^{3/2}}$$

$eval(eq11 \cdot eq22 - (eq12)^2, r1);$

0.09503511653

$eval(eq11, r1);$

0.3263865669

$eval(f1, r1);$

14.87007737

Figure 7. Steiner problem.

In the process of solving it was found that the stationary point for this function is only the point $x^{(0)} = (2.549632; 0.492392)$ - according to the necessary conditions for the existence of the extremum of the function of two variables.

Further we determine whether this point is an extremal. For this the partial derivatives of second order were found:

$$a_{11} = \frac{\partial^2 f(x^{(0)})}{\partial x_1^2},\ a_{12} = \frac{\partial^2 f(x^{(0)})}{\partial x_1 \partial x_2},\ a_{22} = \frac{\partial^2 f(x^{(0)})}{\partial x_2^2}$$

as well as the expression value $\delta_2 = a_{11}a_{22} - a_{12}^2$ at the stationary point.

Since $\delta_2 = 0.095035 > 0$, then according to sufficient conditions for existence of the extremum of functions of two variables, the point $x^{(0)} = (2.549632; 0.492392)$ is the extremum point. Considering that $a_{11} = 0.326386 > 0$, the point $x^{(0)} = (2.549632; 0.492392)$ is the local minimum point, which is equal to 14.870077. Since there are no other points, suspected extremum for the given function in the space R^2, then the point $x^{(0)} = (2.549632; 0.492392)$ is also the point of the global minimum of the function in space R^2. The results coincide with the above (see figure3).

Finally, we present a fragment of the Kepler problem solution by using a genetic algorithm described in detail in [32] (figure 8).

The results are acceptable in comparison with the above (see figures 1 and 2).

```
>
for i1 from 1 to Iter do
Best(GDEC,'JMAX', N) :
ADAPT(adaptability0, N) : num :
adaptmax[i1] := max( adaptability0) :
Adaptsr[i1] := sum(adaptability0['ii'],'ii'= 1 ..N) / N :
NewGeneration(num, GDEC, N) :
Parents(N) : flist : mlist :
ACodBinary(XMIN, XMAX, GDECNews, 0.00000001, N, M) : Gbin :
Crossover1(mlist, flist, Gbin, N) : Gcros :
Mutation(Gcros, 0.008) : Gmut : smut :
ACodDecimal(XMIN, XMAX, Gmut, 0.00000001, N, M) : Gdec :
for i2 from 1 to N do
 Gdec[i2, M + 1] := Func(Gdec[i2, 1], Gdec[i2, 2], Gdec[i2, 3]) :
 end do:
Worst(Gdec,'JMIN', N) :
 Gdec[JMIN, 1 ..M+1] := GDEC[JMAX, 1 ..M+1] :
 adaptability0 := [seq(Gdec[i, M+1], i = 1 ..RowDimension(Gdec))] :
 GDEC := Gdec :
 end do:

> Best(GDEC,'JMAX', N); Rez := GDEC[JMAX, 1 ..M+1];
                    Rez := [ 2.060552202  1.417309921  37.78890309 ]
```

Figure 8. Genetic algorithm.

3. Conclusions and further research prospects

The course "Mathematical Programming" is one of the fundamental training courses for computer science specialties students of institutions of higher education of Ukraine. From a theoretical point of view, during solving optimization problems of this course there are strong interdisciplinary links between relevant topics of mathematical analysis, differential equations, linear algebra, analytical geometry and probability theory, which leads to the formation of students beliefs about the exceptional importance of mathematical education, the organic connection of different sections of mathematics, the importance of mathematics as a science, and as an apparatus for applied disciplines. From a practical point of view, the tasks of the course "Mathematical Programming" are the basis for making optimal decisions in various areas of human activity. Thus, in conditions of limited resources, the tasks of optimal use of minerals, energy, materials, working time, management of physical, chemical, biological, technological, economic, social and other complex processes are relevant.

The methodological aspects of the organization of students individual work in the process of teaching mathematical programming with the computer support contribute to the development of their creative abilities as well as mathematical and IT skills that they use in their professional activities.

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Interdisciplinary problems of mathematical content as a means of teaching programming to secondary school pupils

Interdisciplinary problems of mathematical content as a means of teaching programming to secondary school pupils

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Abstract. The article discusses the main provisions of a practice-oriented approach to teaching programming in a school computer science course. The practice-oriented approach is implemented using a system of practice-oriented problems of mathematical content. The article reveals the classification of practice-oriented problems. Particular attention is paid to Interdisciplinary problems of mathematical content. The article describes the methodology, the main stages and the results of the experiment, during which the effectiveness of the system of practice-oriented problems of mathematical content in the process of formation of pupils' ability to solve programming problems was tested. Using the methods of mathematical statistics, it was proved that the system of practice-oriented problems of mathematical content is more effective than the system of problems given in school textbooks on computer science. During the experiment, the influence of the system of practice-oriented tasks on the formation of pupils' ability to solve programming problems was also investigated. It was proved that the use of the system of practice-oriented programming problems more effectively affects the formation of the ability to solve programming problems. For pupils of the experimental group, the differences between the initial level of formation of the ability to solve programming problems and the final level were significant, while for pupils of the control group, they were insignificant. The results of the experiment confirm the positive influence of the system of practice-oriented problems of mathematical content on the formation of pupils' ability to solve programming problems.

1. Introduction

Under quarantine conditions, it is difficult to ensure that pupils complete all programming tasks. In many respects the effectiveness of their work depends on their motivation. Practice-oriented approach may help to teach graduates to be ready for professional activity [1]. One of the ways to implement the practice-oriented approach is to use practice-oriented problems. Interdisciplinary problems belong to the practice-oriented problems. In our opinion, if we expand the content of school programming tasks at the expense of Interdisciplinary problems, the content of which is related to mathematics, it will positively affect the motivation of pupils and, consequently, the success of learning programming. The state standard of general secondary education [2] states that one of the leading tasks of the school course of computer science is the formation of the ability to develop algorithms for solving problems using modern programming tools [2]. Alferieva, Buzuverov, Kondratenko, Law, Lee, Yu [3–6] note that motivation is one of the important factors that contribute to pupils' mastery of basic concepts and algorithms in programming, and the formation of skills in creating programs. Pupils' motivation largely depends on the teacher's ability to convey the learning material, content and complexity of programming problems. Under quarantine conditions, when pupils learn programming remotely, the role of the content of programming problems increases. If the content of the problems is related to practice, i.e. the problems are "alive" and not abstract, the motivation of pupils increases. Their learning increases accordingly.

2. Analytical review

Increasing attention among domestic and foreign scholars has been drawn towards the problems of informatization of society, the issue of teaching the basics of programming, the formation of competences of prospective teachers of computer science, the features of application of the problem approach in teaching programming in comprehensive schools, teaching programming to gifted pupils. Shevchuk developed a method of teaching programming in the C♯ language to high school pupils. Krivonos and Zhukovskyi developed a system of teaching pupils programming based on a problem-based approach [7]. Zhukovskyi researched the peculiarities of teaching programming to gifted pupils, including for participation in competitions [8]. Horoshko, Mitsa and Melnyk developed a method of teaching pupils to solve Olympiad programming problems [9]. Yatsenko and Chumak investigated the problem of choosing a programming environment for teaching pupils the basics of programming at the initial stage [10]. Bazurin researched the problem of choosind programming environment to learn in secondary school [11], multidisciplinary tasks as computer simulation [12]. Karpenko studies a problem of preparing teacher to learn informatics [13]. Broll, Ldeszi, Zare, Dung, Vlgyesi, Marti, Brown, Sallai and Vanags explored the possibilities of the NetsBlox environment for teaching programming [14].

Since the topic of our study relates to the Interdisciplinary links between mathematics and programming, it is also advisable to analyze current research in the field of teaching mathematics at school. Selby identifies the following basic approaches to learning the basics of programming: code analysis (similar to reading before writing, requires pupils to understand the code before starting to write the code itself); an approach based on the use of blocks (similar to the study of vocabulary, nouns and verbs before composing sentences); pupils use simple blocks before starting to solve more complex problems; the creation of integrated systems, complete immersion in the problem, when pupils develop solutions to non-standard problems, and programming concepts and language structures are introduced only when they necessary for solving the problem [15]. Faraon, Ronkko, Wiberg and Ramberg also offer other approaches to learning programming: coding in a shared learning environment, collaborative learning, lecture-practical, pupil-centered and socio-cultural. They found similarities and differences between the two approaches: pupil-centered and socio-cultural [16]. Alammary identified the following features of blended learning in programming courses:

1) meetings under the guidance of an instructor;
2) face-to-face cooperation;
3) online instruction;
4) online cooperation;
5) independent work online [17].

Thune, Eckerdal, von Hausswolff and Eckerdal analyzes the learning process of object-oriented programming of pupils during laboratory work [18, 19]. The problem of choosing the first programming language and the impact of this choice on the process of learning programming have been studied by Chen, Haduong, Brennan, Sonnert and Sadler [20]. Chang, Chung, Chung, Mingoc, Louwe and Sala researched game technologies for teaching programming [21,22]. Zander, Eckerdal, McCartney, Mostrom, Sanders, Thomas researched the problem of "copypast" programming during the programming learning high school students [23].

The content line "Fundamentals of Algorithmization and Programming" is an important component of the school course of computer science. Ershov illustrate the necessity of teaching programming to pupils in the course of computer science in comprehensive school. Diedinskyi's and Zhukovskyi's research has proved the effectiveness of the system of problems in teaching the basics of programming to comprehensive school pupils [24, 25]. One of the important approaches in teaching programming to secondary school pupils is the practice-oriented approach [3, 26]. The practice-oriented approach is the consideration of the whole course of computer science, each section, each topic and each issue in terms of connection with practice, the environment, the life experience of pupils. The main means of learning, according to the practice-oriented approach, is the situational problem [3, 24, 26]. However, in our opinion, more appropriate term "practice-oriented problem". Given that the main means of learning is the problem, the practice-oriented approach in learning programming can be considered a kind of problem-based approach. Nigmatulina note that the use of practice-oriented problems helps motivate pupils to learn programming [26]. Practice-oriented problems are classified by content: interdisciplinary problems (problems which content is related to other subjects); problems with social content (problems, the content of which is related to the family, education and social life of pupils); professionally-oriented problems (problems, the content of which is related to the future profession of pupils).

Due to the fact that the future profession of most pupils is still unknown, the use of professionally-oriented problems in teaching programming is considered limited. In our opinion, the problems of interdisciplinary content may be more effective. Interdisciplinary problems are divided into groups depending on the subject with which their content is related: problems with mathematical content, problems with physical content, problems with chemical content, etc. There are some close links between programming and mathematics. This is due to the fact that a significant number of fundamental concepts of programming (algorithm, model, etc.) are almost identical for mathematics and programming. Any model is described by mathematical relations (equations, inequalities). The stage of algorithm development is a mandatory stage of creating any program. If algorithmic thinking in pupils is formed at a high level, pupils achieve greater success in program development. But sometimes pupils who have a high level of algorithmic thinking lack the motivation to successfully learn programming. That is why it is advisable to use practice-oriented problems, and more specifically, Interdisciplinary problems. Therefore, in this research we will study Interdisciplinary problems in programming, the content of which is related to mathematics. Therefore, it is advisable to analyze the existing classifications of Interdisciplinary problems in mathematics. It is generaly accepted to distinguish 3 levels of Interdisciplinary problems in mathematics (in complexity): reproduction; connections; reflection.

Scholars note that Interdisciplinary problems contribute to the formation of pupils' qualitatively new system of knowledge based on awareness, efficiency of application in changed and new conditions [20]. The use of Interdisciplinary problems promotes self-determination of pupils, the choice of future profession, motivates in learning. Plotnikova describes the ways of establishing Interdisciplinary links: information and prescription, reproductive, research, problematic [27]. This formed the basis for the classification of Interdisciplinary problems [28]. Adapting this classification to the process of learning mathematics and programming, we obtain the following types of Interdisciplinary problems with mathematical content:

1) information and prescription interdisciplinary problems (learning material in mathematics

and / or programming as basis for solving a problem is used);

2) reproductive interdisciplinary problems - problems to build semantic associations between the learnt material in mathematics and programming;
3) research learnt material - problems that do not have a clear statement, in the process of their solving, pupils must determine either their condition or statement;
4) problematic learning material, that are aimed at understanding hidden connections and relationships.

Smirnova et al., put forward the following requirements for practice-oriented problems in mathematics:

1) use of problem-based learning methods;
2) organization of training in a group, in a team;
3) focus on practical training;
4) taking into account the needs of the labor market;
5) consideration of the requirements of the competence approach;
6) the problem must contain an open chain of successive solutions;
7) focus on the competitiveness of the future;
8) the method of specific situations (case-study)
9) didactic games;
10) solution method;
11) the ability to find an alternative solution
12) the possibility of group evaluation of decisions and organization of individual approach [1].

Alferieva puts forward the following requirements for practice-oriented problems in computer science:

1) the proximity of these problems to life and reality, formulating their conditions in such a way as to give pupils the opportunity to establish a direct connection with the experience gained, as well as with possible future life situations of pupils;
2) giving pupils the opportunity to interpret this situation from the point of view of the participant;
3) the presence of problematic situations and contradictions;
4) solvability in the conditions of existing time frames and individual knowledge, skills and abilities of pupils;
5) the possibility of different options for solving the problem [3].

Based on the requirements of Alferieva, we offer the following requirements for Interdisciplinary problems with mathematical content:

1) connection of the content of the problem with the life and life experience of pupils;
2) giving the pupil the opportunity to consider the problem from the point of view of the participant
3) the presence of problematic situations and contradictions;
4) differentiation of tasks by level of complexity
5) solvability of problems in a certain period of time;
6) invariance of solutions of the problem. All these solutions can be considered correct, but one of them will be optimal from the point of view of algorithm construction [3].

Based on this algorithm, we offer the following algorithm for compiling Interdisciplinary programming problems:

1) determine the place of the problem in the course of computer science, its topic and purpose (in terms of learning programming);
2) formulate levels of complexity of the problem;
3) choose the form of information presentation (text, table, diagram, graph, diagram, etc.);
4) formulate the problem in general;
5) formulate a hint in the problem (if necessary);
6) trial solution of problems by pupils;
7) making adjustments to the condition of the problem.

In the process of developing Interdisciplinary problems with mathematical content, it was decided to focus on the program in mathematics for pupils of grades 6-9, because: starting to learn programming, pupils must have a mathematical apparatus of problems and be able to make a mathematical module of the problem; most of the computational algorithms of the school mathematics course and the introduction to programming are identical; the complexity of programming tasks should correspond to the age characteristics of pupils. In tables 1-4, we offer an approximate content of programming problems related to mathematics. Thus, the subject of the school course of algebra and geometry provides ample opportunities for the development of practice-oriented problems of mathematical content in programming for pupils in grades 7-9.

Table 1. The connection between the problems of mathematics and programming (6th grade).

№	Topic in Mathematics	Topic in Programming
1	Divisibility of natural numbers	Mathematical operations: division, whole division, remainder of division. Determining the digits of two- and three-digit numbers. Determining numbers multiples of x on a given interval.
2	Ordinary fractions	Finding part of a number. Comparison of two numbers that are parts of an integer.
3	Ratios and proportions	Calculation of circle length, circle area. Division of numbers into proportional parts. Object oriented programming. Circle and circle as objects. Properties of a circle and a circle. Coordinate system of graphic components of the programming environment. Create programs that draw a circle and paint it.
4	Rational numbers and actions on them	Arithmetic operations with rational numbers. Branching. Finding the area of definition of rational expression. Divisibility by 0. Cyclic algorithm. Finding the sum and product of rational numbers in the interval.

Table 2. The connection between the topics of problems in mathematics and programming (7th grade).

№	Topic in Mathematics	Topic in Programming
1	Linear equations with one variable	Writing arithmetic expressions in a programming language
2	Whole expressions	Types of variables. Data types. Operations on integers.
3	Functions	Calculate the value of the function based on the entered argument.
4	Systems of linear equations with two variables	Cycles. Solving a system of equations by the method of selection.
5	The simplest geometric shapes and their properties	Determining the affiliation of a point to a figure. Construction of a line, point, ray on the form
6	Reciprocal arrangement of lines on the plane	Construction of straight lines, angles on the form.
7	Triangles	Construction of triangles on the form. Comparison of triangles. Processing two-dimensional arrays containing data about triangles
8	Circle. Geometric constructions	Calculating the radii of circumscribed and inscribed circles around polygons. Comparison of the radii of the circumscribed.

Table 3. The connection between the topics of problems in mathematics and programming (8th grade).

№	Topic in Mathematics	Topic in Programming
1	Rational expressions	Calculating the power of a number. Valid values of x in the denominator of the fraction. Plotting a graph of a function of the form y = k / x by programming
2	Square roots. Real numbers	Types of variables. Data types. Calculating the square of a number. Calculating the modulus of a number. Plotting graphs of species functions
3	Quadratic equations	Linear algorithm. Solving the quadratic equation using Viet's theorem. Branched algorithm. Solving a quadratic equation using a discriminant
4	Quadrilaterals	Linear algorithm. Calculate the length of the side of a square, rectangle, rhombus, trapezoid. Calculation of the midline of a triangle and a trapezoid.
5	Similarity of triangles	Branched algorithm. Determining the similarity of triangles.
6	Polygons.	Linear algorithm. Calculation of the area of a triangle.
7	Solving triangles	Calculation of trigonometric angle functions. Comparison of the sides of right triangles.

Table 4. The connection between the topics of problems in mathematics and programming (9th grade).

№	Topic in Mathematics	Topic in Programming
1	Inequalities	Linear algorithm. Combining and subtracting numerical intervals. Branching. Belonging of a number to a numerical
2	Quadratic function	Cyclic algorithm. Tabulation of quadratic function. Computer graphics. Plotting a quadratic function.
3	Elements of applied mathematics	The concept of mathematical model. Description of a mathematical model using equations and inequalities. Linear algorithm. Calculation of interest. Calculation of compound interest. Using a random number generator. Cyclic algorithm. Programs for processing arrays. Programs for calculating the average value
4	Numerical sequences	Linear algorithm. Calculation of the nth term of the arithmetic progression. Cyclic algorithm. Calculate the sum of n members of the arithmetic progression. Calculate the sum of n members of the geometric progression.
5	Solving triangles	Linear algorithm. Determination of the area of a triangle by the Heron formula, by two sides and an angle, by the radii of inscribed and circumscribed circles. Branched algorithm. Comparison of areas of triangles. Cyclic algorithm. Processing arrays that contain the dimensions of triangles.
6	Regular polygons.	Linear algorithm. Calculation of the area of a circle and its parts. Calculation of the radii of the circumscribed and inscribed circles of regular polygons. Building a circle.
7	Cartesian coordinates on the plane	Linear algorithm. Calculate the distance between two points on a plane given by coordinates. Computer graphics. Coordinate system on the form. Construction of a segment, circle and line on the form.
8	Geometric transformations	Computer graphics. Move shapes on the plane. Animation.
9	Vectors on the plane	Linear algorithm. Calculate the length of the vector given by the coordinates of the beginning and end. Branched algorithm. Comparison of vectors.
10	Initial information on stereometry	Linear algorithm. Calculation of surface area and volume of a rectangular parallelepiped, prism.

3. Method

The aim of the article is to develop a classification of Interdisciplinary problems with mathematical content and determine the impact of these problems on the formation of pupils' ability to develop algorithms and write them in the programming language. The following question was asked during the research: (RQ1) - how much does the mathematical content of programming problems affect the level of formation of the ability to solve programming problems? (RQ2) - how different is the dynamics of the development of the ability to solve programming problems for pupils who use and do not use practice-oriented programming problems? Independent variables in the research were:

1) the main stages of the research - at stage 1st (2 months) programming tasks in the textbook were used, the content of these tasks is traditional, at the end of the stage the pupils' ability to solve programming problems was diagnosed, the selection of pupils of control and experimental groups was carried out, control and experimental groups were compared according to criterion χ^2; at the 2nd stage (formative) in experimental groups lessons were held with the use of practice-oriented programming problems (5 months); at the 3rd stage the diagnostics of the level of formation of skills to solve programming problems was carried out;
2) types of practice-oriented programming problems - interdisciplinary, professionally oriented and socially oriented.

Dependent variable - the level of pupils' ability to solve programming problems.The level of development of the pupils' ability to solve programming problems was differentiated by points as follows: 0 - complete lack of ability to solve programming problems; 1 - low level of ability to solve programming problems; 2 - average level of ability to solve programming problems; 3 - high level of ability to solve programming problems. The level of ability to solve programming problems was determined for each pupil (using diagnostic tasks). The level of development of the pupils' ability to solve programming problems was differentiated by points as follows: 0 - complete lack of ability to solve problems; 1-2 - low level of ability to solve problems; 3-4 - average level of ability to solve programming problems; 5-6 - high level of ability to solve programming problems. Then a summary table was compiled for the whole group and the value of Pearson's criterion was calculated. The groups were then compared according to Pearson's test. Based on statistical processing, it was concluded whether the control and experimental groups are similar.

The research was conducted in 3 stages. At the first the programming problems given in the textbooks on computer science were presented to the pupils of the control and experimental groups. Pupils were given control tasks on programming, the level of pupils' ability to solve programming problems was determined, pupils of control and experimental groups were selected, these groups were compared according to Pearson's criterion. This stage lasted for 2 months. At the second lessons in computer science in experimental groups were conducted using practice-oriented tasks, and lessons in control groups were conducted using tasks from the textbook. This stage lasted for 5 months. At the third stage, the level of pupils' ability to solve programming problems was determined. At this stage, statistical processing of the results was carried out. This stage lasted for 1 month. Pupils of 7-8 grades of gymnasium №1 and secondary school number 17 of Sumy took part in the research. The pupils were 12-14 years old. The number of pupils in the control groups was 150, the number of pupils in the experimental groups was 150. At the first stage of the research, pupils received a diagnostic task, which included questions about the name and surname, class of the pupil. In the same task, pupils were asked to solve three programming problems. For each task correctly solved, pupils received 1 point. Pupils solved problems on a computer in Python using the Thonny programming environment, and then submitted tasks for testing. According to the number of solved problems, the level of pupils' ability to solve programming problems was determined: 0 - no skills, 1 - low level, 2 - medium level, 3 - high level. The programming problems were as follows:

1) the task of creating a program with a linear algorithm;
2) the task of creating a program of choice;
3) the task of creating a program with a loop (for, while);
4) algorithms for processing string data;
5) lists;
6) elements of computer graphics.

At the second (formative) stage of the research, tasks were used that require compiling programs from the following sections:

1) linear algorithm;;
2) branched algorithm;
3) loops (for, while);
4) algorithms for processing string data;
5) lists;
6) elements of computer graphics (module turtle).

Interdisciplinary problems with mathematical content were developed for the pupils of the experimental group. Pupils of the control group solved problems from the textbook. At the third stage, pupils solved diagnostic tasks, which consisted of 6 problems. Pupils received 1 point for each correctly solved problem.

4. Results and discussion

(RQ1) - How much does the mathematical content of programming problems affect the level of formation of the pupils' ability to solve programming problems? The aim of the research was to determine the impact of practice-oriented content of programming problems on the level of formation of pupils' ability to solve programming problems. At the first stage of the research, which lasted for 2 months (September-October 2020), pupils'ability to solve programming problems, i.e. to develop programs was diagnosed. At this stage, diagnostic tasks were used, which consisted of 3 problems: 1) creating a program with a linear algorithm; 2) creation of the program with use of an algorithmic design of branching; 3) creating a program using the algorithmic design "cycle". For a correctly written program, the pupil received 1 point, after which all points were added. According to the sum of points, the level of formation of the pupils' ability to solve programming problems was determined, after which the results were entered into the table. Table 5 and figure 1 show the obtained results at the first (ascertaining) stage of the research. Figure 1 shows the levels of pupils' ability to solve programming problems.

Table 5. The level of formation of pupils' ability to solve programming problems at the ascertaining stage (absolutely indicators).

Level	Experimental group	Control group
High	22	19
Middle	48	34
Low	65	78
Null	15	19

As it can be seen from the diagram, the pupils of the control and experimental groups are characterized by slight differences in their ability to solve programming problems. 14.67 percents of pupils in the experimental group and 12.67 percents of pupils in the control group showed a high level of development of the ability to solve programming problems. 32 percents of pupils in the experimental group and 22.67 percents of pupils in the control group showed an average level of development of the ability to solve programming problems. 43.33 percents of pupils in the experimental group and 52 percents of pupils in the control group showed a low level of development of the ability to solve programming problems. 10 percents of pupils in the experimental group and 12.67 percents of pupils in the control group did not solve any problem

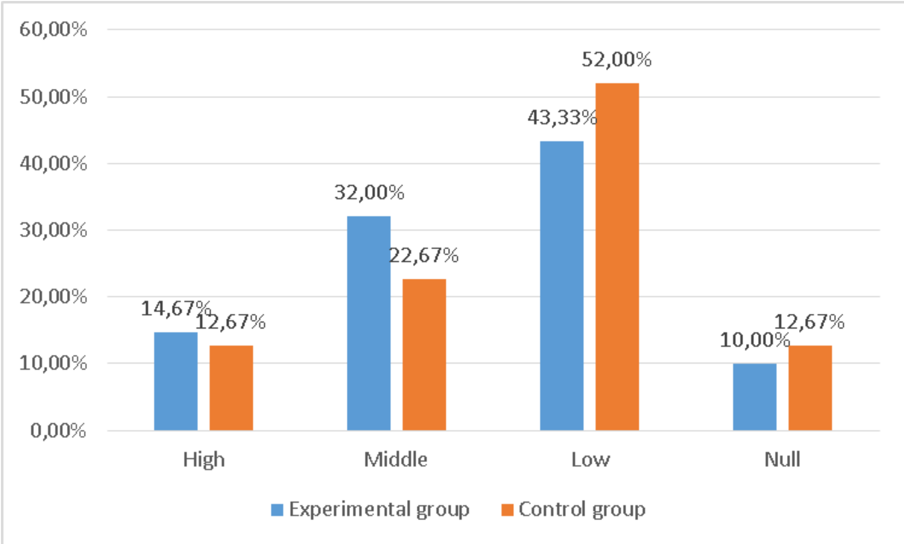

Figure 1. Levels of formation of pupils' ability to solve programming problems at the ascertaining stage (relative performance).

Table 6. Calculation of the Pearson criterion at the ascertaining stage of the experiment.

Number	Interval	Exp. group(f_E)	Contr.group (f_K)	$(f_E - f_K)^2$	$[\frac{(f_E - f_K)^2}{f_K}]$
1	0	15	19	16	0.842
2	1	65	78	169	2.1666
3	2	48	34	196	5.7647
4	3	22	19	9	0.4737
Σ					9.2471

correctly. After that, the diagnostic results were processed using Pearson's test. 4 intervals were determined for the study 0; 0.5-1; 1.5-2; 2.5-3 (statistical calculations are shown in table 6.):

$$\chi^2 = \Sigma[\frac{(f_E - f_K)^2}{f_K}] \tag{1}$$

For this interval, according to Pearson's criterion, the value of χ^2 varies within: $\chi^2 < 9.49$ (slight differences); $9.49 < \chi^2 < 13.3$ (uncertain result); $\chi^2 > 13.3$ (significant differences). The calculated value of Pearson's criterion $\chi^2 = 9.247 < 9.49$, therefore, the experimental and control groups do not have significant differences in the formation of the ability to solve programming problems. Therefore, in these groups it is possible to conduct an experimental research.

At the formative stage of the experiment in the control group, computer science lessons were conducted using programming tasks available in computer science textbooks. The experimental group used practice-oriented problems, the content of which is related to mathematics. The formative (second) stage of the study lasted for 6 months. The control group used problems, which are present in textbook. Textbooks were written by Morze, Barna, Vember and Rivkind, Lysenko, Chernikova, Shakotko etc. Lessons in control and experimental group were taught by the same teachers. During this stage, practice-oriented problems with mathematical content were used.

After completion of the forming phase, the control phase of the experiment was performed. At the control stage of the experiment, pupils of the experimental and control groups were diagnosed. Diagnostic tasks contained 6 programming problems on the following topics:

1) linear algorithm;
2) branching;
3) cycles;
4) string values;
5) lists;
6) elements of computer graphics.

Programs created by pupils were carefully tested. The results of the diagnosis were summarized in a table, where each pupil was assigned a number and the level of ability to solve problems was determined for each pupil. After that, the final table was compiled, which included summary data on pupils of the control and experimental groups. These data are shown in table 7. Figure 2 shows the levels of formation of the ability to solve problems of pupils of control and experimental groups.

Table 7. The level of formation of pupils' ability to solve programming problems at the control stage (absolutely indicators).

Level	Experimental group	Control group
High	34	24
Middle	61	44
Low	52	73
Null	3	9

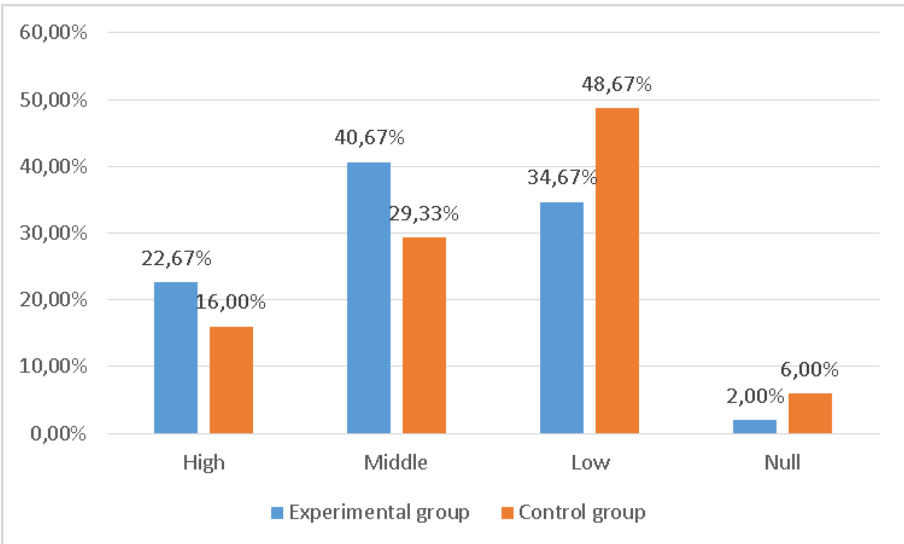

Figure 2. The level of formation of pupils' ability to solve programming problems at the ascertaining stage (relative performance).

Having analyzed the experimental data, we can note the following characteristics:

1) the level of formation of the ability to solve programming problems is different for pupils of control and experimental groups;
2) a high level of formation of the ability to solve programming problems was determined for 22.67 percents of pupils in the experimental group and 16 percents of pupils in the control group;
3) the average level of formation of the ability to solve programming problems was determined for 40.67 percents of pupils in the experimental and for 29.33 percents of pupils in the control groups;
4) 34.57 percents of pupils of the experimental group and 48.67 percents of pupils of the control groups showed a low level of formation of the ability to solve programming problems;
5) zero level was was determined for 2 percents of pupils in experimental group and for 6 percents pupils in control groups.

The results of criterion Pearson's calculation are shown in table 8.

Table 8. Calculation of the Pearson criterion at the control stage of the experiment.

Number	Interval	Exp. group(f_E)	Contr. group(f_K)	$(f_E - f_K)^2$	$[\frac{(f_E-f_K)^2}{f_K}]$
1	0	3	9	36	4.0
2	1	52	73	441	6.041
3	2	61	44	289	6.5681
4	3	34	24	100	4.1667
Σ					9.2471

Thus, the level of formation of the pupils' ability to solve programming problems is higher for pupils of the experimental group. Next, we performed statistical processing of the results of the research according to Pearson's test. The obtained experimental value is $\chi^2 = 20.78 > 13.3$ (critical value). From this we can conclude that the identified differences in the pupils' ability to solve programming problems are significant, and therefore, the level of formation of the pupils' ability to solve programming problems for pupils of the experimental group is significantly higher than for pupils of the control group. From this we can conclude that the use of programming problems, the content of which is related to mathematics, has a positive effect on the pupils' ability to solve programming problems.

(RQ2) - How different is the dynamics of the development of the ability to solve programming problems for pupils who use and who do not use practice-oriented programming problems? To answer this question, the results of the ascertaining (first) stage and the control (third) stage of the study were analyzed in detail and compared.

The results were summarized in table 9. The first two columns of table 3 show the levels of formation of the ability to solve problems of programming for pupils of the experimental group at the I and III stages of the experiment. The table shows that for the pupils of the experimental group there is a positive dynamics of increasing the level of formation of the ability to solve programming problems. Thus, the number of pupils who demonstrated a high level of development of this skill increased by 12. The number of pupils who showed an average level of formation of this skill increased by 13. The number of pupils who showed a low level of development of programming skills decreased by 13. The number of pupils who failed to solve any problems decreased by 12.

Positive dynamics was also observed for pupils in the control group. The number of pupils who showed a high level of development of the ability to solve programming problems increased

Table 9. The dynamics of changing the level of pupil's ability to solve programming problems (absolute indicators).

Level	Exp.gr.(I stage)	Exp.gr.(III stage)	Cont.gr.(I stage)	Cont.gr.(III stage)
High	22	34	19	24
Middle	48	61	34	44
Low	65	52	78	73
Null	15	3	19	9

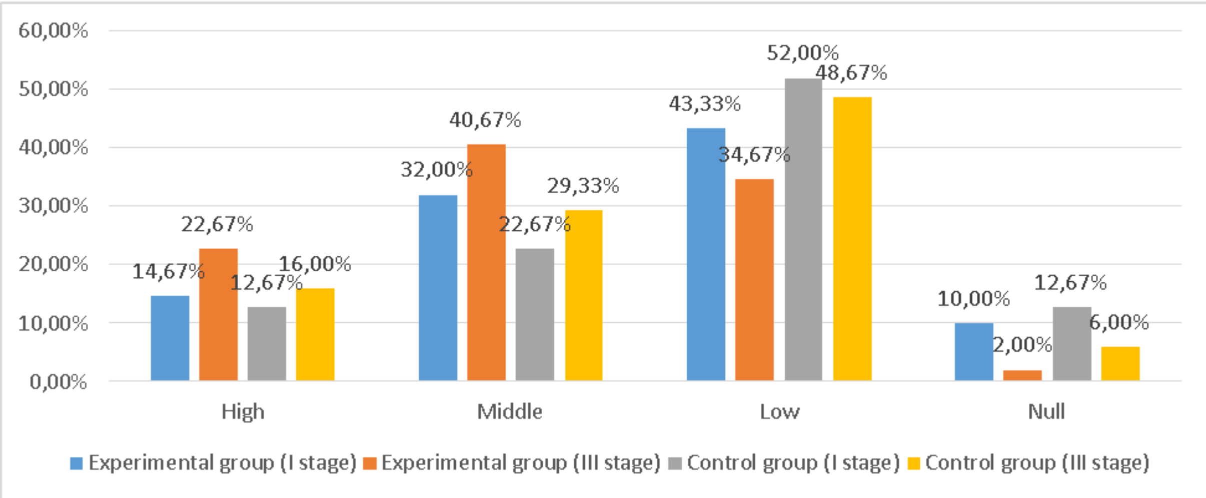

Figure 3. Dynamics of growth of the level of formation of the ability to solve programming problems (relative performance).

by 5. The number of pupils who demonstrated an average level of development of the ability to solve programming problems increased by 10. The number of pupils with a low level of ability to solve problems decreased by 5. The number of pupils who do not know how to solve problems decreased by 10.

Summary results in percentage are shown in figure 3. Based on the analysis of the diagram (figure 3) it was found that the pupils of the experimental group showed a higher dynamics of growth in their ability to solve programming problems: the number of pupils with a high level of such skills increased by 6 percents (in the control group - by 3.33 percents), the number of pupils with an average level of this skill increased by 8.67 percents (in the control group - by 6.66 percents), the number of pupils with a low level in the experimental group decreased by 8.66 percents (in the control group - by 1.33 percents), the number of pupils without this skill decreased by 8 percents (in the control group - by 6.67 percents). Thus, there were some differences between pupils of the control and experimental groups in the dynamics of growth of the ability to solve programming problems.

Then the statistical results of the study were processed. For this purpose, the levels of formation of the ability to solve programming problems for pupils of the experimental group at the first and third stages of the experiment according to Pearson's test were compared. The results of criterion Pearson's calculation for experimental and control groups are shown in table 10, table 11.

Table 10. Calculation of the Pearson's criterion for experimental group.

Numb.	Interv.	Exp.gr.(ac.stage)	Exp.gr. (contr.stage)	$(f_E - f_K)^2$	$[\frac{(f_E-f_K)^2}{f_K}]$
1	0	15	3	144	9.6
2	1	65	52	169	2.6
3	2	48	61	169	3.5208
4	3	22	34	144	6.5455
Σ					22.2663

Table 11. Calculation of the Pearson's criterion for control group

Numb.	Interv.	Contr.gr.(ac.stage)	Contr.gr.(contr.stage)	$(f_E - f_K)^2$	$[\frac{(f_E-f_K)^2}{f_K}]$
1	0	19	24	25	1.3158
2	1	78	73	25	0.3205
3	2	34	44	100	2.9412
4	3	19	24	25	1.3158
Σ					5.8933

The obtained value was $\chi^2 = 22.26 > 13.3$, which indicates that the level of pupils' ability to solve programming problems differed significantly at the first and third stages of the experiment. We also compared the level of formation of the pupils' ability to solve programming problems in the control group pupils at the first and third stages of the experiment according to the criterion χ^2. The obtained value is $\chi^2 = 5.89 < 9.49$, so we can conclude that the level of formation of this skill for pupils of the control group has not changed significantly.

5. Threats to validity and study limitations

Our research was limited by quantitative and territorial scope. A limited number of pupils attending schools in one city took part in the research. However, the number of these pupils was quite sufficient to obtain reliable statistics. With regard to RQ1, we found that at the first stage, a significant number of pupils in the control and experimental groups did not solve any programming problem (12.67 percents and 10percents, respectively). It was also found that about half of the pupils have a low level of ability to solve programming problems (43.33 percents of pupils in the experimental group and 52 percents of pupils in the control group). There were also differences in the number of pupils who showed high (14.67 percents of pupils in experimental and 12.67 percents of pupils in control groups) and medium level (32 percents of pupils in experimental and 22.67 percents of pupils in control groups) of formation of the ability to solve programming problems. The differences between the pupils of the control and experimental groups were not significant, it is proved by the methods of mathematical statistics. At the second stage of the research, pupils solved programming problems, and the content of these problems differed. Pupils of the experimental group solved practice-oriented problems of mathematical content, pupils of the control group - problems from the textbook. Some pupils developed programs in Python (206 pupils), some pupils - in Free Pascal (Lazarus programming environment) (94 pupils). The choice of programming language depended on what language the pupils studied in a particular lesson in a particular school. The ratio of the number of pupils in the control and experimental groups who studied Python is about the same (100 and 106 pupils, respectively). The number of pupils who studied Free Pascal (50 and 44 pupils, respectively) is similar. At the third stage of the study, we found that the level of formation of the ability to solve programming problems increased for the pupils of the control and experimental groups. 22.57 percents of pupils in experimental group and 16 percents of pupils in control groups showed a high level of the ability to solve programming problems. The average level of formation of this skill was found for 40.67 percents of pupils in the experimental group and 29.33 percents of pupils in the control group. 34.67 percents of pupils in the experimental group and 48.67 percents of pupils in the control group showed a low level of the ability to solve programming problems. 2 percents of pupils in the experimental group and 9 percents of pupils in the control group did not solve any problem.The identified differences in the levels of formation of the ability to solve programming problems were assessed using Pearson's test. It was determined that $\chi^2 = 20.78$, so the level of formation of the ability to solve programming problems is higher for pupils of the experimental group and differs significantly from the level of formation of these skills for pupils in the control group.

As for RQ2, we determined the positive dynamics for pupils in the control and experimental groups. However, the pupils of the experimental group were characterized by a greater increase in the level of formation of the ability to solve programming problems than for the pupils of the control group. The identified differences were analyzed and evaluated using Pearson's test. The experimental group (first and third stages of the experiment) was characterized by an increase in the level of formation of the ability to solve programming problems: pupils with a high level of these skills made from 14.67 percents to 22.67 percents (8 percents), pupils with have an average level of these skills made from 32 percents to 42.67 percents (8.67 percents). The number of pupils with a low level decreased from 43.33 percents to 34.67 percents (by 8.66 percents), and the number of pupils with zero level decreased from 10 percents to 2 percents (by 8 percents). Pearson's test proved that these changes were significant. For the control group (first and third of the experiment) it is also possible to note an increase in the level of formation of the ability to solve programming problems: the number of pupils with a high level increased from 12.67 percents to 16 percents (3.33 percents), the number of pupils with average level increased from 22.67 percents to 29.33 percents (by 6.66 percents). Accordingly, the number of pupils with a low level decreased from 52 percents to 48.67 percents (by 2.33 percents) and pupils with a zero level - from 12.67 percents to 6 percents (by 6.67 percents).Pearson's test showed that these changes were not significant.

6. Conclusions

The main purpose of our research was to determine the impact of practice-oriented problems of mathematical content on the formation of pupils' ability to solve programming problems. In our research, we used a practice-oriented approach to the study of programming in high school, which was implemented as a system of Interdisciplinary problems in programming, the content of which is related to mathematics. The pupils of the experimental group showed the level of skills in solving programming problems than the pupils of the control group. The differences, which identified, are significant. This is proved by the methods of mathematical statistics (Pearson's criterion). The students of the experimental group demonstrated positive dynamics of growth in the level of skills in solving programming problems. The methods of mathematical statistics prove this (Pearson's criterion). As a result of the experiment it was proved that the use of a system of problems of mathematical content has a positive effect on the formation of pupils' ability to solve programming problems. In the future, the research can be significantly expanded at the expense of pupils from other cities of Ukraine, as well as pupils of pedagogical universities majoring in "Secondary Education (Computer Science)". The obtained results contribute to the development of a system of practice-oriented programming problems, the content of which is related to mathematics and other subjects.

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Project-oriented approach to the study of robotics according to the concept of STEM education

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Project-oriented approach to the study of robotics according to the concept of STEM education

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Abstract. The importance of studying robotics in the conditions of the Fourth Industrial Revolution for solving the problem of training qualified STEM specialists is substantiated. The technique of using a project-oriented approach in the process of studying technologies for creating robotic systems is disclosed. The stages of implementation of the method based on the project of a maneuverable robotic platform are given. The methodology proposes a step-by-step development of a completed functional product, divided into several stages. At each stage, students get acquainted with the corresponding functions of the software and the theoretical aspects of electrical, physical, mechanical phenomena necessary to solve the problem at this stage. An important aspect of this technique is also the acquisition of practical work skills: drawing up diagrams, soldering individual electrical components to the board, laying electrical connections and manufacturing parts using 3D printing. Work on solving problem-oriented complex tasks allows to consider the problem as a collective, which will create the necessary prerequisites for professional activity. These capabilities of the project-oriented approach allow to implement the key concepts of STEM education: the research process, mastering the technology of manufacture and implementation of technical creativity on the basis of basic mathematical knowledge.

1. Introduction

The intensive development of robotics, which we can observe today, is completely subordinated to the ideology of the Fourth Industrial Revolution [1, 2]. According to this ideology, automated production, data exchange and production technologies are developing and merging into a single self-regulating system, with the least or no human intervention in the production process [3].

The use of self-regulated production systems inevitably leads to changes in the labor market and the emergence of new professions and requirements for them. Because robotic production requires specialists who can carry out its development, research, maintenance, repair, control, design and commissioning. This leads to an increase in the requirements for a modern specialist capable of innovation and the solution of non-standard professional tasks based on the development of research competencies [4].

These trends in the development of IT technologies and their mass introduction into production processes inevitably lead to changes in the education system and its methodologies, in particular, the introduction of STEM education. This contributes to the transition to new approaches to the organization of training [5] and the introduction of new technologies based on the achievements of scientific and technological progress [6].

The works of N. Soroko, S. Semerikov, I. Mintii, M. Mintii and others are devoted to the study of new approaches to the organization of STEM education [7, 8]. The development of methods for teaching future teachers about robotics was carried out, in particular, by N. Valko and V. Osadchyi [6]. Despite the widespread coverage of the problem of introducing STEM education, the issue of developing a methodology for studying technologies for creating robotic systems remains relevant.

A feature of the educational process for the study of robotics is the need to conduct it in various fields of knowledge: materials science, electrical engineering, microprocessor technology, programming, production technology, Internet of things technologies, conducting and processing the results of experiments, and others. This is best realized in the general concept of STEM education as a synthesis of science, production technology, engineering and mathematics [9, 10].

However, training stands and materials on the market are either too expensive or too limited in functionality, training materials or techniques. On the other hand, working with a ready-made robotic complex does not allow to master the methodology of development of robotic systems. In the study of the finished complex, the modernization process is ignored. Also out of consideration is the rapid replacement of the element base, the study of the proposed algorithms and methods of designing structural components. Therefore, one of the ways to teach robotics is to use a project-oriented approach that provides solutions to these problems with greater efficiency [11, 12].

2. Using of a project-oriented approach in the study of robotics

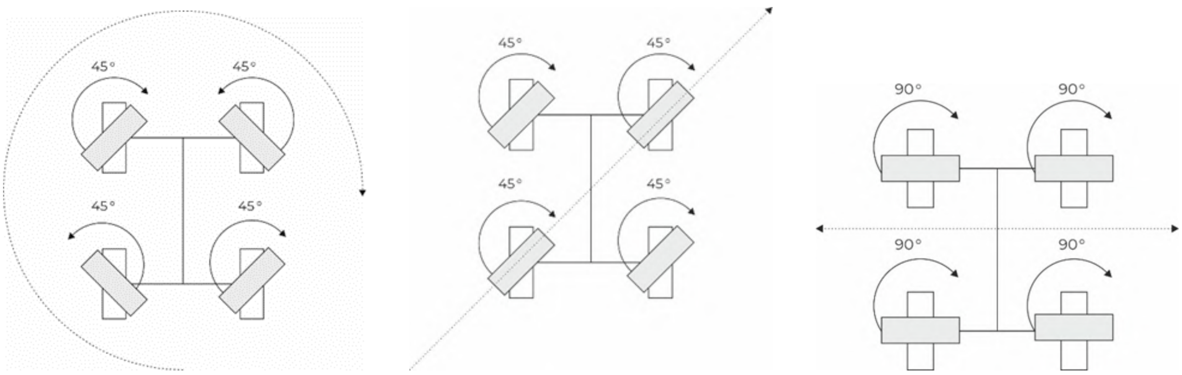
The use of a project-oriented approach in the study of robotics allows to fully implement the main provisions presented in the concept of the development of STEM education, according to which “educational methods are aimed at developing competencies that are relevant in the labor market. In particular, these are critical, engineering and algorithmic thinking, data analysis skills, digital literacy, creativity and innovation, communication skills” [13].

In our proposed method of using a project-oriented approach in the study of robotics, at the initial stage, a problem is selected and subgroups of students are formed who will solve the task. The task is selected from a wide range of practical problems, for example, the development of a robotic arm, or a running gear of work, or an aero-hydroponics system, smart home and smart city elements, robotic environmental monitoring systems.

Students in the process of studying technologies for creating robotic systems independently develop and produce a training stand in accordance with the chosen option for a practical task. Using the developed training stand, students have the opportunity to explore its properties and ways of modernization. The theoretical material is explained on the basis of the implementation of the stages of practical development. This provides a thorough understanding of the theoretical material regarding the functioning of robotic systems, their physical essence based on the acquisition of practical skills in their design and research.

This study presents a methodology for teaching robotics using a project-oriented approach on the example of the task of developing a maneuverable robotic platform. At the initial stage, the teacher invites students to explore the existing types of selected solutions to this problem, their strengths and weaknesses, known to the teacher or independently found by students. For example, the development of a running gear is chosen, which will have mechanisms for turning each individual wheel by 90 degrees and the ability to control the speed and direction of rotation of each wheel. This will allow to make a 360-degree turn on the spot (figure 1a) and change the motion vector at any angle, for example: at an angle of 45 degrees (figure 1b) or at an angle of 90 degrees (figure 1c).

In the process of implementing a project-oriented approach [14], an important point is to hold a discussion among students, where they should discuss problematic issues as much as possible and get answers to their own questions and questions of the teacher. If students are not able to answer these questions on their own, the task of the teacher is to push them to the correct answer and help justify the decision. For example, in solving our applied problem, such key questions will be the following: it is necessary to choose which element base to use, what materials for the body to choose, what type of wheels is better to choose in this case, what problems may arise, what characteristics are planned to be included in the design, which How will the wheels turn?



(a) (b) (c)

Figure 1. Scheme of rotary capabilities of the maneuvering platform.

At the next stage, students learn the basic functions of working with a CAD system to develop drawings of details of the design of the robot. To do this, they are provided with sufficient instruction to be able to make a drawing of the part. Such brief instruction does not allow you to fully master all the functionality of the software product. On the other hand, students are provided with additional educational material in the form of video tutorials, which will allow them to fully master this product on their own. Preference is given to free CAD systems and systems that allow you to work on a project in a team, such as Autodesk Fusion 360. In this case, each student develops his own node, or several nodes, such as servo mounts, batteries, solar panels, motherboards or sensors. The result of solid modeling with Autodesk Fusion 360 is shown in figure 2.

The developed drawings are exported in stl format with their subsequent preparation for printing and setting up the printer in (for example, in the Ultimacer Cura environment) (figure 3) and printing on a 3D printer. This allows you to consolidate the knowledge gained in the process of studying design technologies using CAD-systems and visualize the process of manufacturing the body and the development and design of relevant design documentation and flow charts of the technological process.

Students adjust and modernize their components until the chassis acquires a complete look with the specified indicators (figure 4).

The next stage in the implementation of the project-oriented method is the development of a structural-electrical circuit diagram with its maximum required functionality. As in the case development phase, first there is a discussion of the conceptual scheme and the nodes that should be included in it.

The component base, power supply, microcontroller, sensors are selected and their characteristics are discussed. At this stage, the theoretical material is consolidated to understand the principles of connecting the selected microcontrollers, their settings for operation, and port

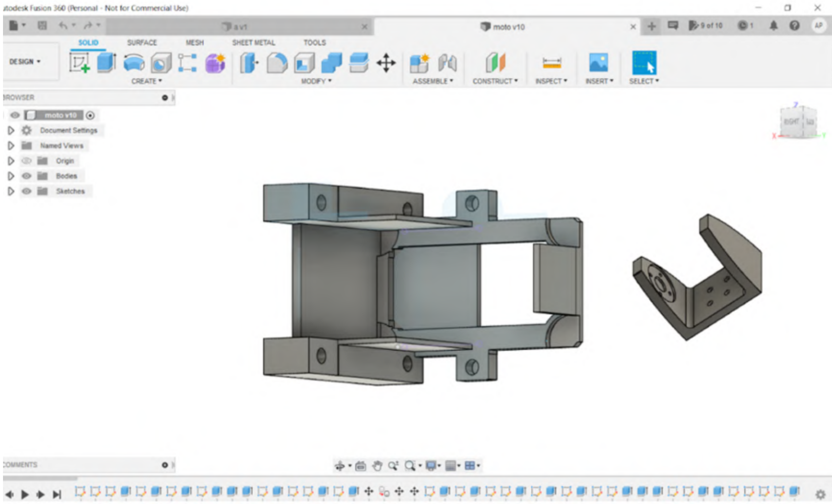


Figure 2. The result of solid modeling Autodesk Fusion 360.

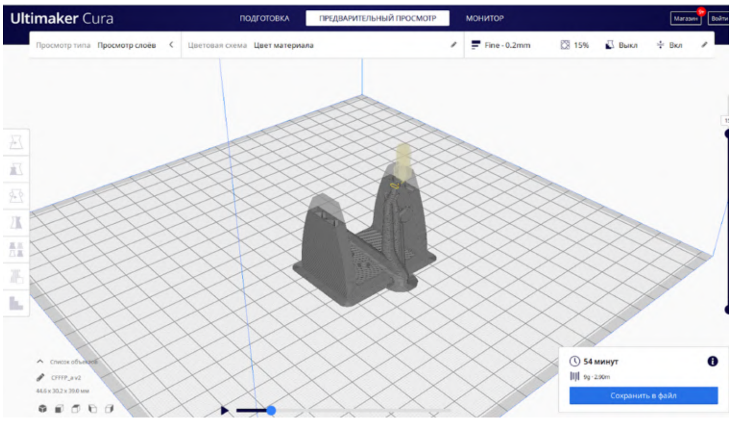


Figure 3. Preparation for printing details in the Ultimacer Cura environment.

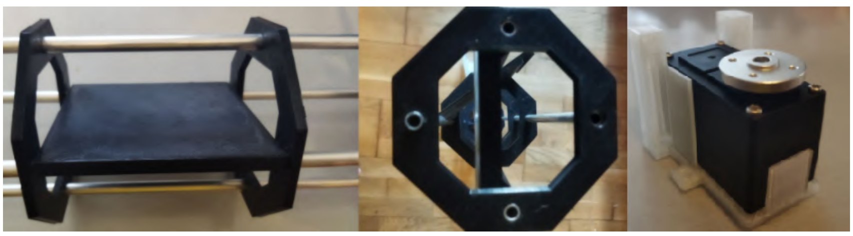


Figure 4. The general view of the received details of a design of the case and fastening of the servodrive.

assignment. In the process of implementing this stage of the project, first a structural-electric circuit diagram is built (figure 5), and then an electrical circuit diagram (figure 6) is built using CAD tools. Preference is given to free software products with the ability to work in a team and the ability to emit electrical circuits.

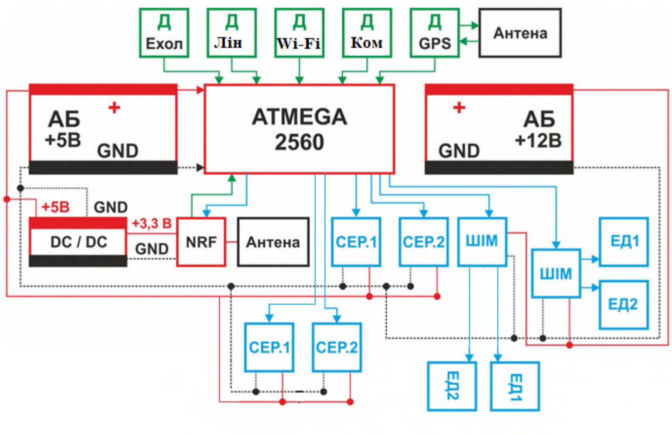


Figure 5. Structural schematic diagram of a robotic training system.

To test the algorithms of this system and develop a software solution in C++, students are offered to develop a simulation circuit diagram in Tinkercad. This will allow you to implement the basic elements and work out their interaction. This approach allows them to visualize the work of key components of the system, their relationships and prepares students to work with the physical model. The simulation capability also allows electrical connections to be visually laid out and signals flow through them, reducing further errors in the design and programming of the training stand.

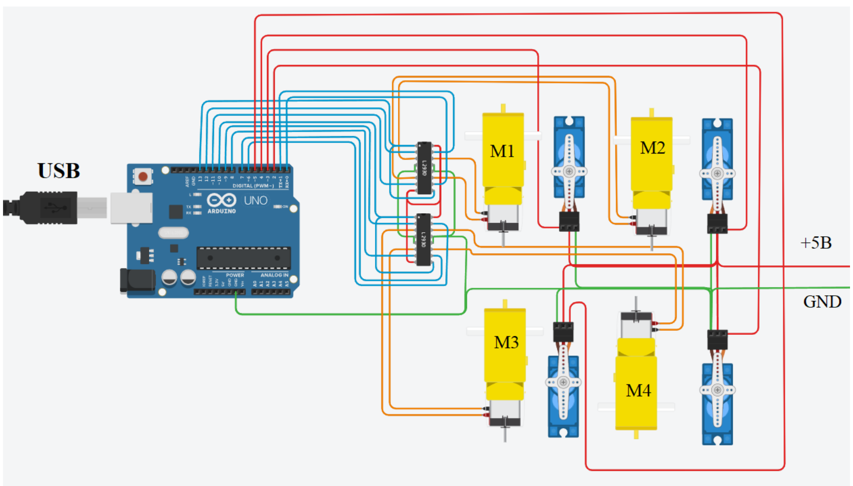
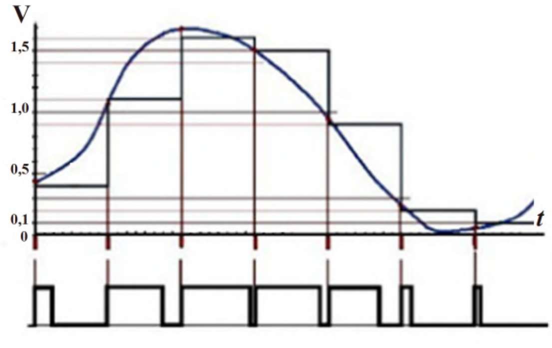
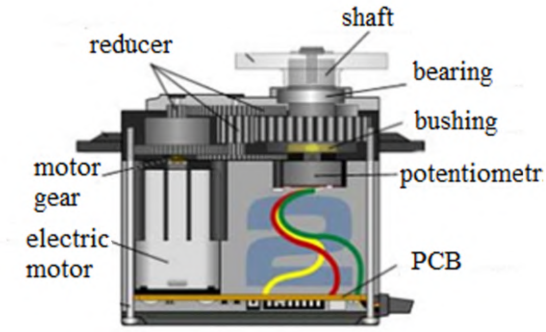


Figure 6. Electrical schematic diagram of the control system of servomotors and collector motors in Tinkercad.

This stage also offers an explanation of the theoretical material related to the operation of controllers, pulse-wide modulation drivers and servo structure. The student is invited to consider the key components of the system, their physical and software principles of operation (figure 7a), possible design options (figure 7b).



(*a*)



(*b*)

Figure 7. The key components and processes of the system.

At the final stage, the electrical and physical models are combined in a single stand (figure 8), motors, servos are connected, they are calibrated and the functionality of software algorithms is implemented. This allows you to consolidate and develop skills and abilities acquired at the stage of simulation, as well as physically visualize the work of the system, its movements and reactions to the environment.

Figure 8. General view of the robotic training platform.

The developed design and algorithms are further studied by students in real circumstances, the shortcomings of designs and algorithms are sought and eliminated, their interrelations are investigated. Students are invited to study their implemented projects, for example, on the subject of motor overload, structural rigidity, cross-country ability, reaction speed. After the completion of this stage, the final conclusions are formulated, in which the key role is played by the results achieved by the students and the ways of modernization proposed by them. Since the goals and conclusions of the study are formed together with the students, this allows students to increase their competence in using the methodology of the scientific approach, from setting tasks to analyzing their results for reliability.

Thus, the use of a project-oriented approach allows students to gain not only theoretical knowledge and practical skills in robotics, but also develop creative abilities.

It should be noted that the implementation of projects of robotic systems requires students to have basic multidisciplinary training. As a result of questioning students, discussing problematic issues, conducting test tasks and analyzing the work performed, it was possible to identify difficulties that students found difficult to cope with. Among them, we can note the insufficient level of school knowledge in physics, which created difficulties in the design of electrical circuits and the development of structural elements. At the same time, it should be noted that mastering the basic tasks of creating software for robotic platforms did not cause significant difficulties for students.

A survey of students confirmed their interest in performing this type of task. When asked if they were interested in carrying out creative projects to create robotic systems, only ten percent of the respondents answered that they did not care, the rest of the students gave a positive answer. The expediency of using a project-oriented approach is also confirmed by a significant increase in student activity in laboratory classes.

Our study, of course, needs further development, in particular, the correct choice of tasks, the assessment of the quality of their performance from the point of view of problems of interdisciplinary connections. However, already at this stage, it can be argued that it is expedient to use a project-oriented approach as a basic one in the methodology for studying robotics.

3. Conclusions

Thus, the use of a project-oriented approach in the process of studying robotics ensures effective research work of students, not limited to standard educational stands, educational materials and software.

The use of self-developed educational stands allows to systematize information about the object of research conducted on a specific practical task and to strengthen the cognitive activity of students. This approach allows you to significantly raise the self-esteem of students and increase their motivation to learn. They gain confidence that they can manufacture and implement a complex system on their own or independently master some aspects of working in CAD systems that were not presented directly by the teacher.

Working on solving problem-oriented complex tasks allows us to consider the task as a collective one, which will create the necessary prerequisites for professional activity, since in real life most types of work take place in a team. Also, this approach allows the student to find exactly the niche in the project that appeals to them the most: programming, development of structural details or the creation of electrical circuit diagrams.

These capabilities of the project-oriented approach allow to implement the key concepts of STEM education: the research process, mastering the technology of manufacture and implementation of technical creativity on the basis of basic mathematical knowledge. Prospects for further research are to improve the methods of teaching robotics based on a project-oriented approach using the potential of interdisciplinary interaction.

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Professional competencies of future software engineers in the software design: teaching techniques

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Abstract. The article is devoted to one of the competence components of a mobile-oriented environment for professional and practical training of future software engineers. It is shown that the introduction of higher education standard 121 "Software Engineering" for the first (bachelor) level of higher education in Ukraine has generated a number of training quality assurance problems associated primarily with the low level of detailed competencies and program learning outcomes. By solving these problems, the detailed design of the system of professional competencies for future software engineers is developed. The article deals with the approaches to developing one of the most important special professional competences of future software engineers – the ability to participate in software design, including modeling (formal description) of its structure, behavior, and processes of functioning. Based on a historical and genetic review of the software engineering training practice of future software engineers in the USA, UK, Canada, Australia, New Zealand and Singapore, recommendations for choosing forms of training organization, selection of training content, ways of students' and teachers' activities in software engineering, modeling and designing tools; assessment of the appropriate competence formation level are formulated. The example of organizing design training in conditions close to industrial-studio training is considered. The problems of transition from architectural to detailed design and project implementation are shown. Prospects for further development of this study are to substantiate the third (after requirements engineering and design engineering) engineering component of software engineering – the software construction.

1. Introduction

The approval in 2018 of the higher education standard 121 "Software Engineering" for the first (bachelor) level of higher education [1] in the light of the new accreditation procedure for educational programs in Ukraine gave rise to two main problems, the solution of which was entrusted to the guarantors of educational programs:

(i) The standard provides an extremely high degree of freedom in interpreting the content of competencies and learning program outcomes, which leads to significantly different and non-harmonized educational programs and plans, which are assessed by National Agency for Higher Education Quality Assurance (Ukraine) experts according to the same vague quality criteria. At the same time, similar foreign standards (university, state and world standards) have a high level of detailing of competence components and criteria for assessing their formation – just as in the USA, Australia and Japan quality criteria for educational programs are detailed for a certain field of education, not applied to all. The lack of clear criteria for quality assessment, specific to the field of knowledge, generates risks of violation of the principle of academic integrity in their evaluation.

(ii) The high rate of changes in the content of the technological component of software engineering training along with the attempt of educational program compilers at least respond to the requirements of industry, if not ahead of them, leads to an instrumental bias in software engineering training – up to the leveling of the universal competences essential for sustainable professional development of a software engineer. Such a bias leads to the indistinguishability of software engineering from other specialties in the branch of knowledge 12 "Information Technology" and professional disorientation of entrants and students.

Solving these problems requires systematic mastering of the international experience in software engineering training in its genesis [2, 3] and designing a system of professional competences (content, indicators of formation and diagnostic tools), both general [4] and special [5].

Among the special competences of an software engineer, those that reflect the "essence and spirit" of software engineering – the specificity of software engineers' professional activity, which cannot be acquired during training in other specialties of the "Information Technologies" branch of knowledge – deserve special attention. Thus, the recommendations for the development of software engineering undergraduate curricula define the competence to find compromises, the essence of which is to reconcile conflicting design goals, to find acceptable compromises in cost constraints, time, knowledge, existing systems and organizations: "Students should engage in exercises that expose them to conflicting and changing requirements. ... Curriculum units should address these issues, with the aim of ensuring high-quality functional and nonfunctional requirements and a feasible software design" [6, p. 21].

Finding compromises and reconciling contradictions is a traditional engineering design activity, which is not mandatory for all information technology professionals, but is key for software engineers. In the standard [1] it corresponds to the special competence K14 – "the ability to participate in software design, including modeling (formal description) of its structure, behavior and functioning processes". The formation of the ability to design software is critical in determining whether a graduate of an software engineering educational program is a software engineer.

A review of software engineering educational programs available at Ukrainian Higher Educational Institutions websites shows that software design training is accomplished in three main ways:

(i) artificial introduction of design elements in different courses in close connection with the tools by the example of solving typical simplified problems of a certain industry;
(ii) spontaneous teaching of design elements during the internship on real tasks;
(iii) training of software modeling tool (usually UML).

Only a small number of educational programs have attempted to take into account the global experience of design training organization based on synergetic combination of academic and industrial forms and methods of training.

Therefore, the purpose of our paper is to provide a historical and genetic review of software design training practices of future software engineers.

2. Teaching software design: international experience

Vladimir N. Pelevin correlates the special competence K14 (ability to participate in software design, including modeling (formal description) of its structure, behavior and functioning processes) singled out in standard [1] with the ability and readiness to carry out system design, which includes system engineering design, applied software and computer networks [7, p. 14].

Modeling and analysis can be considered the basic concepts of any engineering discipline, as they are important for documenting and evaluating design solutions and alternatives [6, p. 31]. Software design refers to issues, methods, strategies, presentation methods and patterns used to determine how to implement a component or a system [6, p. 32].

David Carrington [8] defines that software design is the stage of software development, during which the specification is transformed into a structure suitable for implementation. Design training should cover both the design object and the process by which this object is created [8, p. 547].

Chenglie Hu [9] puts a number of questions about what software design is:

1. *Can software design be defined using an engineering metaphor?* "For instance, design of a bridge must comply with appropriate laws of physics, but designing software has no laws of any kind to abide by, at least in theory. The architecture of a bridge is much discernible with naked eyes whereas software is intrinsically intangible, and, at core, it is an abstract entity of which we only work with various representations. In practice, an engineering design must precede formal construction of the bridge whereas construction of software can take place without an explicit design. Yet perhaps the most serious difference is that once construction commences, changes to the specification of an engineering product may not be allowed whereas changes to software requirements are generally expected and can indeed happen anytime during the software's life cycle." [9, p. 63].
2. *Can a computer program itself be considered a piece of art?* "It probably can, but not always against the same set of criteria. The reason is that a designer can, for instance, trade violation of some design principles for resolving pressing issues in hand due to software constraints of different nature. Design seeks a balance among extendibility, compliance with design principles, and accommodation of software constraints, and can thus be elegant and artistically appealing in many different ways." [9, p. 63].
3. *Can software design be defined by design activities?* "In fact, design activities are diverse; many are certainly technical, yet some can be social too, but none is likely to be standardized to characterize design or its process." [9, p. 63].
4. *Can software design be defined by design artifacts to be produced or design phases to go across?* "IEEE Standard 1016-2009 (for Information Technology – Systems Design – Software Design Descriptions) specifies the required information content and organization for software design descriptions to be used for communicating design information to its stakeholders. However, the way to describe a design and document information content and organization can range from the more traditional "big design up front" all the way to "the code is my design". When professionals do not agree on design artifacts, neither will they likely have consensus on design phases. In fact, agile practitioners believe that design is not only highly iterative, but emergent, and models often lie. Thus, only coding, running tests, and refactoring the code reveal the truth about a design." [9, pp. 63–64].

Chenglie Hu connects the design process with design thinking: "Professionals have long suspected that designing software might well be a cognitive process that happens inside one's brain at a speed faster than lightening, and the essence of design, then, is a rapid modeling and simulation process that proposes solutions and allows them to fail" [9, p. 64]. Clive L. Dym, Alice M. Agogino, Ozgur Eris, Daniel D. Frey, Larry J. Leifer) listed the mental abilities that are often associated with good project thinkers, including: tolerate ambiguity, maintain sight of the big picture, handle uncertainty, make decisions, think as part of a team, and think and communicate in several languages of design [10, p. 104].

As a result, Chenglie Hu defines software design as a systematic, intelligent process in which designers generate, evaluate, and specify concepts for a software system whose structure and function achieve clients' objectives or users' needs while satisfying a specified set of constraints [9, p. 64].

The design process is both extremely creative and extremely complex, so it is not surprising that there are few truly outstanding designers. However, the demand for new projects is very high, and to face it, each architectural and engineering industry has developed a set of principles that enable designers with average abilities to create design solutions of acceptable quality. Although Software Engineering is much younger than other engineering fields, it has also accumulated some knowledge of how to create projects, and future software engineers need to master this knowledge, so design teaching should be an integral part of their training [11].

"Exceptional individuals are born with a sense of what makes a good design. Most of us must see examples of good design before we can come up with good design on our own. Therefore, we teach design by example, providing students with design sketches and then much feedback on their attempts to refine the design." [12, p. 33]

Robert M. Graham in 1970 in his article [13] proposes a method of teaching design that introduces a single key idea and explores its implications in an environment that consciously ignores the issue of efficiency. Once the logical implications of this idea have been fully developed, the additional key ideas are combined one by one and their implications are explored. Next, the effectiveness and other real limitations are considered, examining the consequences of each. This procedure is continued until a realistic project is reached. In addition, a specially designed and documented case is used to illustrate project development.

David M. Weiss in [14] presents a later (mid-1980s) experience of design software teaching invariant to the applied design methodology. His approach involves two stages: first, students are introduced to the principles underlying the methodology and the experience of applying these principles to small, well-defined tasks. In the second stage, students are offered a real task that they must solve independently in a simulated work environment, receiving guidance only on methodological issues. The first stage is presented in the form of a series of lectures. The second is supervised by a design expert. As a result of the first stage, students gain some understanding of the principles underlying the design methodology, see examples of application of these principles and practice their application on educational examples. After the first stage, students are able to use design techniques under the guidance of an experienced designer in the process of his almost daily interaction with students. As a result of the second stage, students gain enough experience in design to carry it out with less guidance, communicating with an experienced designer about once a week [14, p. 1156].

At the kick off meeting of the project, the roles they will play during the project are distributed among the students. Students get acquainted with the sequence of the main stages of the project, get a list of documents that have to be presented, and the procedure for their preparation. Students are also provided with brief notes on the configuration of management procedure, a description of the responsibilities and the composition of the quality assurance team. Each student must develop and document at least one module of the system [14, p. 1157]. D. M. Weiss notes that students were dissatisfied with the fact that they focused on design, but did not develop the finished product due to the complexity of the design task (however, a simpler task would not provide an opportunity to demonstrate and master all necessary design techniques and methods). In general, the students felt that they had mastered the design methodology, but were disappointed that they did not create a single line of code. To overcome this disappointment, students can be invited to continue working on the project in the next semester [14, p. 1158].

D.M. Weiss provides the following recommendations for the organization of software design training [14, p. 1159]:

(i) students must be advised by a design specialist who can ensure strict adherence to the methodology;

(ii) the design task must be quite complex, and students are not allowed to simplify it;

(iii) students should be encouraged to make their own project decisions: none of the teachers should interfere in the decision-making process;

(iv) the size of the student group should be small to allow teachers to closely monitor the progress of each student.

Ehud Lamm [15] notes that the goal of a software design course is to develop software design skills by teaching the basic concepts of software engineering needed to study and analyze alternative software projects.

Computing Curricula 2020 [16, p. 120] defines the following competencies related to software design:

1. Present to business decision-makers architecturally significant requirements from a software requirements specification document.
2. Evaluate and compare tradeoffs from alternative design possibilities for satisfying functional and non-functional requirements and write a brief proposal summarizing key conclusions for a client.
3. Produce a high-level design of specific subsystems that is presentable to a non-computing audience by considering architectural and design patterns.
4. Produce detailed designs for a client for specific subsystem high-level designs by using design principles and cross-cutting aspects to satisfy functional and non-functional requirements.
5. Evaluate software testing consideration of quality attributes in the design of subsystems and modules for a developer/manufacturer.
6. Create software design documents that communicate effectively to software design clients such as analysts, implementers, test planners, or maintainers.

The core of knowledge about software design Chenglie Hu [9] proposes to divide into 2 categories: design process knowledge and knowledge of design-enabling techniques – the latter includes design patterns. Knowledge of the process is defined by the author as "knowledge about commonly-recognized design phases we go through as well as paradigms or methodologies we use to progress in a design process or to produce design artifacts" [9, p. 65]. Analysis of software requirements is part of the architectural design process, which covers the functional and behavioral aspects of architecture. An architectural design concerns not only what the system is, but also what the system does. The next stage of design – non-architectural (detailed) design – is to modulate and detail the interfaces of design elements, their algorithms and procedures, as well as the types of data needed to support the architecture and meet the requirements. Non-architectural design determines the functionality and structure of the software at a high level of detail, but insufficient for implementation. The design process also involves managing the production of design artifacts to ensure the correct and accurate implementation of design ideas and solutions. Chenglie Hu believes that the design process is not complete if the project is not implemented in the code [9, p. 66].

Keith Pierce, Linda Deneen, Gary Shute [11] believe that the key issue of design training is a rational choice among many alternative solutions [11, p. 220]. "It seems to us that instruction in design would improve dramatically by making this single modification in how we teach: presenting alternative design strategies and alternative solutions derived using these strategies, presenting the criteria for judging the quality of the alternatives, and forcing students in laboratory exercises to make and justify a choice among them." [11, pp. 220–221] The authors divide the design methods into low-level (used to design small modules – the choice of ordered and unordered arrays, between recursion and iteration, etc.) and high-level (used to decide on the organization of software modules).

Yanxia Jia and Yonglei Tao [17] consider modeling to be a central component of the quality software development process. When teaching software design, teachers should emphasize the creation of an appropriate model to consider the problem and the use of model properties to design a solution [17, p. 702].

The authors [17] identify the following key concepts:

- *modeling* – the process of creating an abstract, graphic or mathematical description of the design problem, during which the developer replaces a complex and detailed real situation with an understandable model that reflects the essence of the problem;
- *the evolution of the model* in the iterative process of development tends to preserve the form of representation, while *the transformation of the model* involves a change in the point of view from which the design problem is considered, and a change in the structure of the design model;
- *code refactoring* is the process of changing the code of a computer program in order to preserve its ability to develop, improve its readability or simplify the structure, while maintaining existing functionality. Refactoring training not only gives students practical programming skills, but also helps them understand the most important principles of Software Engineering;
- *design patterns* can help developers solve certain design problems, as well as improve existing projects.

Redesigning software to better reuse or acquire other qualities is an illustration of model transformation. The gradual transformation of the model requires students to constantly assess the gap between what has been done and what needs to be done. Such activities are especially useful for the formation of students' ability to evaluate the existing solution and analyze the benefits and costs [17, p. 705].

Software design patterns are often used to solve a common problem through a "general" approach to it. Johan van Niekerk and Lynn Futcher [18] point out that the design pattern provides a conceptual model of the best practice solution, which in turn is used by developers to create a concrete implementation of their task. The use of design patterns has a number of advantages: 1) the pattern provides a guide to best practice; 2) the use of the pattern provides developers with a common "dictionary" for easy and clear discussion of complex design concepts. Due to these and other advantages, design patterns are often studied in software design courses [18, p. 75].

A pattern can be described as "a solution to a problem in a context" [18, p. 77]:

- the context is a recurring situation in which a pattern is used;
- the problem refers to the goal you are trying to achieve in this context, but it also refers to any constraints that occur in the context;
- the problem should be a recurring problem;
- the solution provides a general design (core solution) that extracts the essence of the solution to resolve the problem for the given context and constraints.

Design patterns provide software designers with three main advantages [18, p. 78]:

(i) the solution is known to be sound because it is time-tested;

(ii) benefits and drawbacks of a pattern are known in advance and they can be taken into account while sketching the solution;

(iii) patterns establish a common vocabulary that can ease communication between different stakeholders.

Chad Williams and Stan Kurkovsky [19] emphasize that the process of learning to use appropriate software design patterns can be made creative by transforming the design process itself into a constructivist learning environment. To do this, they propose not to limit the subject of student projects and create conditions for students to get out of the comfort zone by applying new hardware platforms and interfaces to them. The interim evaluation of the project was performed according to the level of expediency and the number of used design patterns, and the final - according to the level of creativity of the whole project.

A framework can be defined as a semi-complete program that contains certain fixed components that are common to all programs in the problem area, along with certain variable components that are unique to each program created from it. Most commercial software is developed using frameworks by extending and customizing the standard common features they provide. Zoya Ali, Joseph Bolinger, Michael Herold, Thomas Lynch, Jay Ramanathan and R. Rajiv Ramnath [20] indicate that developers who know the principles of object-oriented design do not use in the development of software a particular framework, focusing simply to “make it work”. Adapting to a new framework can be a challenge for novice developers because using design patterns in a new framework can lead to poor design and misuse of the framework. The authors [20] propose a three-step process of learning design using frameworks, aimed at overcoming this problem:

(i) First, students are asked to design their program using object-oriented design. Using the formulation of the problem, students are encouraged to “object-oriented thinking” and use of previous experience to create objects, classes, responsibilities, relationships, methods, and other UML entities.

(ii) Next, students are asked to rewrite the program using design patterns. One of the patterns is the Model-View-Controller (MVC) pattern. The idea of this model is to isolate the logic of the program domain from the way the data is presented to the user (ie the user interface of the program) so that these two very important components of any program can be developed, implemented and maintained separately.

(iii) Finally, students are asked to adjust the use of the design pattern according to the chosen framework.

To better understand the framework and seamlessly integrate the project with the framework, students need to learn the design patterns dictated by the framework and compare them with the standard design pattern. “Similarly, the UML is a natural complement to design patterns, providing a means for students and teachers to communicate them.” [21, p. 42]

Teaching UML encourages a downward approach to software engineering: first, students are taught to identify software requirements, then to transform requirements into software architecture, low-level design, and finally implementation. UML is often used as the “lingua franca” across these lifecycle phases and heavy emphasis is placed on the students producing high quality, syntactically and semantically correct UML diagrams [22, p. 19].

Ali et al. [20] offer a methodology that will give students the opportunity to take advantage of the framework in the implementation of their project [20, pp. S3G-3–S3G-4]:

1. Paraphrase the problem statement and extract all the nouns and verbs from it. The nouns serve as candidate objects, classes and attributes, while verbs serve as responsibilities.
2. Merge the extracted nouns into classes. This may require discarding irrelevant nouns or nouns representing the same thing.
3. Merge extracted verbs into classes, instances and responsibilities.
4. Assign responsibilities by identifying required methods to complete those responsibilities.
5. Walk through the scenario to ensure that each scenario is supported by methods and identify the collaborations between them.

Design is inherently an interdisciplinary subject, influenced by a large number of human factors, so teaching design is not only a process of teaching design itself, but also a process of further developing students' social skills [9, p. 70]. Stanislaw Jarzabek notes that team-oriented project courses provide an opportunity to learn the principles of Software Engineering when their application is really necessary and profitable, and suggests the following classification [12, pp. 31–32]:

(1) Industrial attachments in which students work on real-world problems in industrial settings.
(2) Project courses in which students work on problems in various application domains under supervision of faculty members, experts in a given domain. Sometimes such courses build on real-world problems provided by industry.
(3) Project courses in which students learn advanced software design principles and apply them in their projects. As faculty members need scrutinize in detail design artifacts to provide feedback to students, such projects must be supervised by faculty members specializing in software engineering, and well-versed with problem and solution domain students work with.
(4) Projects developed from scratch versus projects in which students extend existing software.
(5) Projects based on a specific software platform such as .NET, JEE, service, mobile device or Facebook.

"Team work, communication and writing skills can be trained in all of the above project courses. Other skills are quite difficult to accommodate in the frame of a single project course. For example, in project types (1) and (2) the goal is to expose students to the reality of fuzzy, ill-defined and changing requirements. Fuzzy requirements and software design are not only the two hallmarks of software development, but also hard and wicked problems that are difficult to teach in the frame of a single course. Project courses that expose students to fuzzy and changing requirements tend to be less structured and rigorous than courses that teach students application of design principles. When teaching application of design principles (project course type (3)), we should give students sample design sketches, and lots of detailed feedback on their initial attempts to refine the design. Supervisors need be intimately familiar with a problem domain and design solutions to provide effective guidance for students. This may be quite difficult in projects types (1) and (2)." [12, pp. 32]

Students write a final report in which they document project plans, development process, architectural and detailed (non-architectural) design decisions. Each team is given one hour to present their work. Teachers evaluate students on the basis of design quality, ability to evaluate design decisions and justify their choice in view of the stated attributes of quality - reuse, extensibility and effectiveness of the query evaluation strategy [12, pp. 37–38].

Learning by way of active feedback is an effective way to teach students to design on a large scale. Examples provided to students may include software architecture sketches, API specifications, and illustrations of how to apply design techniques. Some students clearly follow a specific example to create their own design solutions, while others learn from examples, but then innovate, experiment with ideas, and offer their own design techniques. In both cases, it is important that students clearly understand the essence of the design methodology. Although the lectures highlight the theory of design principles, communication between teams and teachers leads to their understanding. At the beginning of their studies, students are especially often mistaken and need a lot of feedback and constructive discussions to perform proper design [12, p. 38].

Damian A. Tamburri, Maryam Razavian and Patricia Lago [23] noted that this approach helps students in learning the main challenges of software design [23, pp. 61–62]:

(a) *accountable and rational design decisions* – students learn how to reason and really be accountable for their own design decisions;

(b) *collaborative design* – students can brainstorm constructively with "opponent" teams, reaching a deeper understanding of the designer role;
(c) *iterative design* – students learn from other people's mistakes and solutions pro-actively revisiting their own design, which is far more effective than any of the many examples we used in the previous years;
(d) *"social" design* – students learn to make teamwork effective and cope with critical reviews driven by different backgrounds and expertise (hence offering feedback from very different perspectives).

J. L. Murtagh and J. A. Hamilton Jr. [24] describe the organization of project-oriented learning, determining the following desired learning outcomes of students:

(i) Students should use the knowledge of previous computer science courses to develop moderately complex computer projects, based on clear, consistent and reasonably complete requirements presented by the teacher in the project task.
(ii) Students must develop high-level (architectural) projects of programs and their interfaces and obtain the approval of the teacher before moving on to detailed design. Students must demonstrate that all requirements for the project assignment have been allocated to specific parts of the architectural design.
(iii) Students must develop a detailed (non-architectural) project of software and all interfaces and obtain the approval of the teacher before embarking on implementation (ie writing code).
(iv) Students should develop a test plan for each project. The test plan should demonstrate how all software requirements will be tested, and include a software testing schedule.
(v) Students should develop documentation that shows how their software and test plan meet the requirements of IEEE / EIA 12207 [24, pp. 5.577.2–5.577.3].

"There is an interesting parallel between teaching and learning on the one hand and design patterns on the other. Design patterns are little more than good practice; they are the culmination of tried and tested techniques for designing software that exhibits desirable properties like flexibility and reuse. On several occasions, undoubtedly along with other software designers, we have solved a design problem only to later find that what we have actually done has been to apply a particular design pattern. This is reassuring, but the point is that we have subconsciously applied what is accepted to be good practice. With teaching, we often do the same; we unknowingly use a technique that has its roots in established education theory. In both cases, however, adopting proven techniques is important to yield quality results." [21, p. 40]

Ian Warren [21] methodically substantiated the learning outcomes of software design training [21, pp. 41-42]:

1. *Identify and describe the objectives of software design.* Design objectives include correctness, robustness, flexibility, reusability and efficiency. Students should appreciate that software should not only be correct, but that the latter 4 non-functional objectives are also important.
2. *Interpret and construct UML models of software.* The UML, being a standard industry notation, is an obvious choice for communicating design knowledge. Essentially, students should be able to read and write UML models.
3. *Explain the notion of design patterns and describe a subset of patterns.* Design patterns embody proven design solutions. Students should appreciate that using patterns fosters an engineering approach as opposed to one that solves problems from first principles.
4. *Apply patterns to solve real-world problems, making sensible tradeoffs where necessary.* Awareness of patterns is important but is no substitute for being able to apply a pattern to solve a problem. This objective is concerned with deeper, functioning knowledge.

5. *Apply newly acquired and developed programming skills.* Students have functioning knowledge of fundamental OOP but have limited knowledge of Java class libraries and more advanced aspects of programming. This objective aims to equip students with stronger implementation skills.
6. *Work with relatively large software projects.* Similarly, students' experience of developing software is typically confined to small programs involving a few classes. Exposing students to larger projects is good preparation for final year project work and industrial practice.

I. Warren singled out methods that are effective for teaching software design:

- *problematic questions such as "what will happen if ...?".* I. Warren gives an example of the use of such questions when considering UML class diagrams and, in particular, relationships and multiple constraints: "By presenting a class diagram and asking students what the multiplicity constraints really mean engages students; they have to interpret the diagrams and assess their own understanding rather than sitting passively where it is too easy for students to think they have understood. When we see that students have understood, we can change the constraints; subtle changes on a diagram can have significant changes in meaning." [21, p. 43];
- *role-playing games*: "In reviewing the basic ideas of object-orientation we have students acting as objects and playing out scenarios showing how links between objects are formed dynamically and how messages are processed. ... Role play leads naturally into documenting scenarios using UML; once students have exercised a scenario, they document it using a UML object interaction diagram. From an initial class diagram and an interaction diagram generated from role play, we are able to explore the issue of well-formed models, where different views should ultimately be mutually consistent." [21, p. 43];
- *active learning*, from the introduction of activity fragments during lectures to sessions of interactive and problem-oriented activities as a means of acquiring functional knowledge by students about design patterns [21, p. 48];
- *peer-learning* "is manifested by students having a formal learning partner who they pair-program with, and with who they collaborate on coursework tasks. In addition, students work in small groups on problems in the classroom." [21, p. 48].

Jon Whittle, Christopher N. Bull, Jaejoon Lee, and Gerald Kotonya [22] offer another alternative to traditional learning, studio-based education, which brings to the forefront reflective practice as a way to develop design skills. In the studio, students are invited to critically reflect on their own and others' design, using a variety of techniques such as mentoring, design criticism, mutual mentoring, and concerted evaluation. The studio course is usually, but not always, taught in a room designed for this purpose, ie in the studio. Physical studio is considered a key element because it allows students to constantly demonstrate their own work, which over time encourages reflective practice. The studio also encourages frequent and informal interactions between students, which leads to mutual learning [22, p. 12].

In the table 1 a comparative description of the environment of studio and traditional learning is shown.

When pursuing a studio course at the University of Lancaster, the authors [22] found that students did not use formal modeling (modeling using formalized descriptions, such as UML, where exact notation and correct syntax are used), using informal modeling using or special notation (for example, drawing figures on a board (figure 1), pen on paper or using a digital sketching tool), or free interpretation of a recognized modeling language (for example, drawing a diagram of UML classes without proper syntax) [22, p. 16]. Although the students in the studio did little formal modeling, they regularly came up with informal models. These include both UML models (typically usage variants and class diagrams), sketches (eg. high-level architecture,

Table 1. Comparative characteristics of studio and traditional learning (according [22, p. 15]).

Aspect	Studio course	Traditional course	Example: Lancaster University's study course
Physical environment	There is a physical room (i.e., the studio) which is open and reconfigurable providing a variety of group, individual and social spaces	Standard lab	Dedicated lab with 24 hour access, maintained by students themselves
Management of studio	Rules regarding use of the space should not be restrictive	Lab tightly controlled by University	24 hour access; food/drink allowed; students have admin rights
Modes of education	Teaching staff play a coaching/mentoring role rather than being didactic	Students given a prescriptive list of documentation to produce	Students were told to produce "as much documentation as needed"; there was no prescription on what kinds of diagrams or notations to use
Awareness	Placing work on display (as works-in-progress or final products); visibility of work helps students see each other's work.	No special consideration	Students used mobile whiteboards in the studio to display design work, which was left up for the duration of the project
Critique	Ongoing critique is used for providing feedback and developing ideas. It should take place in multiple ways (formal and informal, group and individual, peer and staff)	Provided only as part of weekly meetings with project supervisor	Provided on a continuous basis using a variety of methods: individual and group demos/presentations, informal coaching, peer critique, critique from external assessors (e.g., companies) and formal judging
Culture	A studio culture should be social and foster sharing, and yet should be sensitive to sup- porting a good work ethic	Lack of a dedicated lab meant that students typically only met at prearranged times	Students used the studio as a home, leading to serendipitous interactions and a feeling of 'belonging' to a cohort
Inspiration	When designing, students should be encouraged to be creative in their designs and solutions	Project specification decided a priori by academic staff	Students come up with their own project ideas in a facilitated creativity brainstorming session

user interface design sketches), and process-based models (eg. burnout diagrams used in flexible design) [22, p. 17].

In the studio approach, students engaged in modeling as much as needed and when they needed it. The students did not try to create fully-fledged models for the function they were

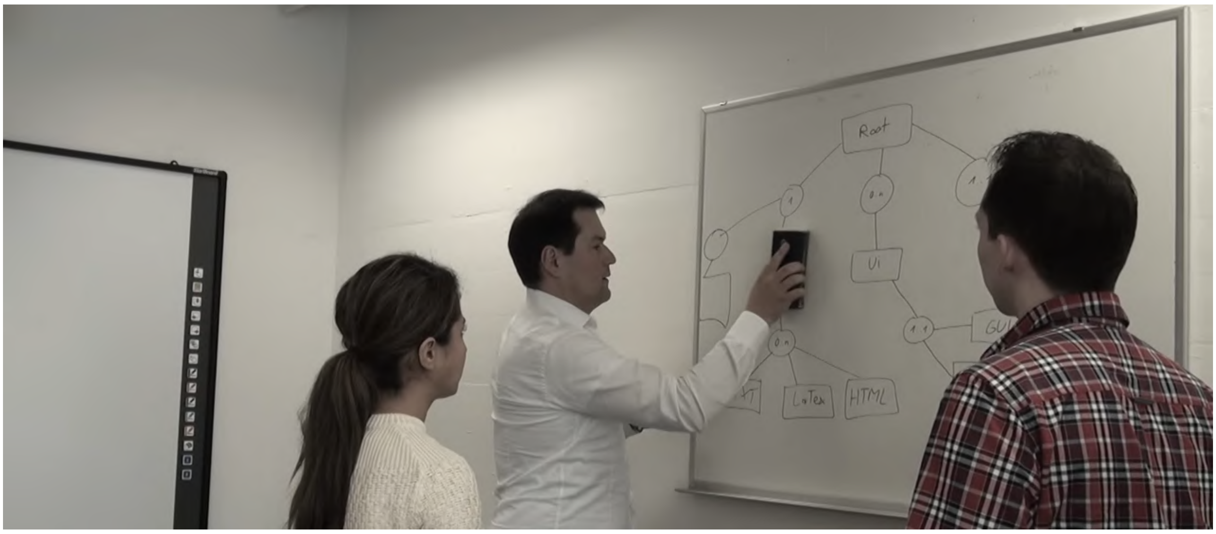

Figure 1. Informal modeling on the board.

going to implement – the models were used mainly for brainstorming and design. Once the design was thought out enough to allow the team to move on to the next stage of development, the models did not change, but continued to be used as a design artifact: students typically used them either to remind them of what they were doing, or as a background "noise", which in some way helped them work in a group [22, p. 18]. This approach is actively used by software design experts – for example, Marian Petre and André van der Hoek in the guide [25] used informal modeling to summarize their own design experience (figure 2).

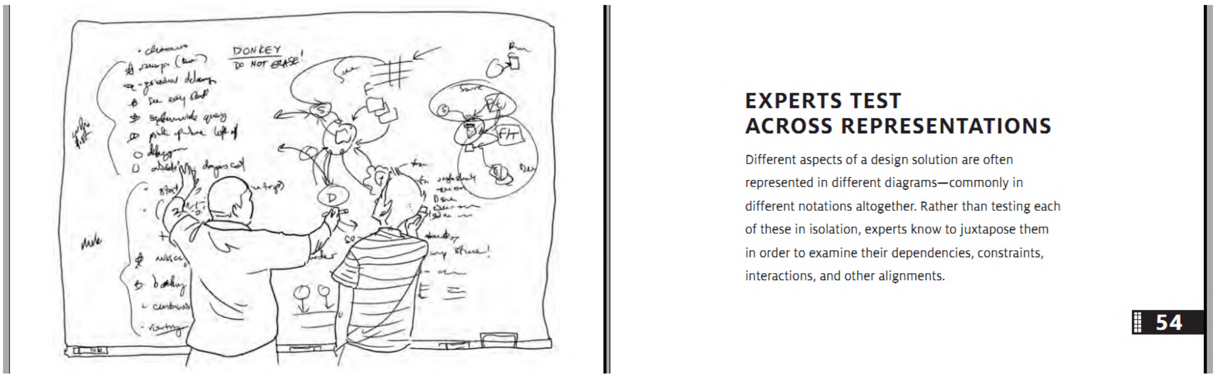

Figure 2. Fragment of the design guide of M. Petre and A. van der Hook [25] in the form of a sketch project.

The combination of informal and formal modeling is possible with the help of flexible modeling tools (figure 3), which after creating an informal sketch provide an opportunity to move to formal modeling without changing the tool [22, p. 17]. The authors of the studio course [22] believe that students should be introduced to a number of design methods, learn to apply these methods in practice and through reflective practice to encourage them to learn about the pros and cons of these methods: "Indeed, one could argue that the most important thing to teach is the culture of reflective practice itself. If students learn how to reflect, they will become reflective practitioners and can apply those skills to any new method or approach which they are faced with in their future careers." [22, p. 20]

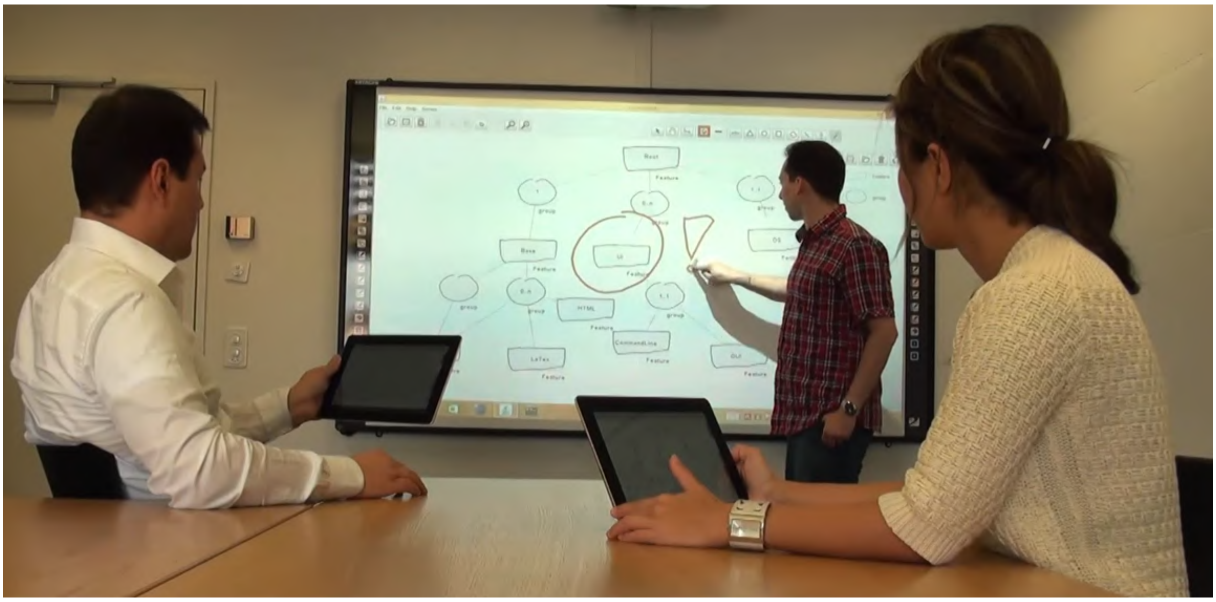

Figure 3. Simulation using FlexiSketch Team.

M. Petre and A. van der Hook [25, pp. 148–158] recommend the following actions for reflection in software design:

(i) Do not allow deviations to minor issues when discussing the project, regularly check yourself, "where am I and what am I doing?"

(ii) Based on a deep understanding of the fundamental concepts of design "keep up to date": remember what design decisions have already been made, why they were so and what other decisions need to be made.

(iii) Thinking about what is not designed: identifying and considering design limitations, to identify the design excessively or insufficiently.

(iv) Periodically stop to look at the project as a whole, asking yourself whether the goals of customers, user perceptions, the market itself, etc. have changed.

(v) Anticipate different options for the future, analyzing the economic feasibility of determining where to invest – in methods, tools, resources, design alternatives – in order to save efforts in the future.

In the study of design Chenglie Hu recommends to consider the following [9, pp. 69-70]:

1. Students' technical competency and cognitive strengths can significantly impact the outcomes of learning design. For this reason, the goal of teaching software design is not to make every student a designer, but for students to experience what it might take to produce a good design while acquiring individually achievable design skill and ability by seeking pedagogy that can maximize learner's technical and cognitive potential.
2. For relatively small scale design problems, test-driven development renders opportunities to express modeling ideas directly in code, allowing more effective evaluation of design tradeoffs and committing less design errors than using diagrams.
3. Learning "small-scale design" (writing related methods, appropriate data encapsulation, using good method names, etc.) is probably much less challenging than studying design in general to study structural stability, which requires design compromises to apply knowledge of the design process. The minimum basic design skills (with an appropriate level of project

thinking) that graduates must acquire may include the ability to effectively begin design, decompose a task, perform design iterations with sound design compromises solutions, and implement the project in code.

4. Students cannot effectively acquire the ability to design and learn project thinking if they do not solve design problems of appropriate complexity.
5. Despite the lack of universal formulas or design recipes, data analysis (identification of entities and their relationships) and process analysis (detection of actions and logical flows) are critical to understand what information to use and how it is transformed.
6. Correctly documenting a design – timely, not post factum – is a necessary skill, however, whether students should use UML or how accurately they use the language to document the model is not so important. It is advisable to acquaint students with some classic diagrams, encouraging their creative use.
7. For the final assessment of students' learning outcomes, it is advisable to combine traditional classroom tests (to make sure "they know this") with complex design homework, which must be solved individually or in teams of two with careful monitoring and evaluation of finished design products made by students, but also the quality of project implementation, documented in student reports.

3. Conclusions

Summarizing the results of the study has provided an opportunity to draw the following conclusions:

1. Software design is a type of engineering design, which combines two components – creative and systemic-technical. The formation and development of engineering creativity is a technology for mastering the best examples of projects in the process of design activities close to production. The result of the design is an updated and adapted sample (typical project, or design pattern) or an original new design (project). In this regard, significant potential for the development of methods for teaching software design to future software engineers is available in related research in other fields of engineering (including construction, mechanical and computer) and art (in particular, architecture, painting).
2. In teaching software design, special attention should be paid to supporting students in design, the theoretical foundations of which are acquired in the form of lectures, in the form of practical classes, studies, course projects, etc. to solve real problems of complex software design. This places an additional requirement on design teachers to work in software development industry or to be closely connected with its customers.
3. Software modeling plays a key role in its successful design. At the same time, compliance with the requirements for the use of accurate formal descriptions of models in the design process does not significantly affect the quality of design: the ease of use of accurate formal and flexible informal models is comparable. Therefore, it is advisable to use flexible methods and tools of modeling, in which the construction of formal UML diagrams is performed on an informal sketch project.
4. The transition from architectural design based on the chosen pattern to non-architectural (detailed) design may require adapting the pattern to non-design realities in the form of software design tools, such as the framework. Therefore, despite the fact that software design is possible without its design, the appropriate design result is at least a constructed software prototype: as part of the software life cycle, design is the driving force of its development – it is constantly performed until decommissioning.
5. Assessment of the formation of competence in software design involves testing individual knowledge and team skills of design in the process of solving a complex design problem.

Design artifacts such as sketch designs, formal models, design documentation, prototypes and more are important for this. Therefore, the defense of projects is an appropriate form of evaluation.

Prospects for further development of this study are to substantiate the third (after requirements engineering and design engineering) engineering component of software engineering – *software construction.*

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Proteolytic processes in organism of different age rats exposed to xenoestrogens

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Abstract. Endocrine disrupting chemicals (EDCs) are a group of compounds that affect the endocrine system, frequently found in everyday products and epidemiologically associated with several diseases. The human population is now ubiquitously exposed to EDCs in daily life. The main way of getting xenoestrogens to the body is the contaminated food. The effects of xenoestrogens on the proteolytic processes of different age rats were determination. The experiments were conducted on Wistar rats exposed to exogenous estrogen for 45 days. At the beginning of the experiment 3-month-old pubertal animals and 6-month-old sexually mature rats were involved. The research materials were organ tissue and blood serum of the rats. The objects were indexes of activity of trypsin and its obligatory inhibitors α1 - antitrypsin (α1-AT) and α2-macroglobulin (α2-MG), cysteine cathepsins B and L, the molecules of middle mass (MMM) level. In summary, the eating food contaminated by exoestrogens led to changes in the proteolytic system and the development of endogenous intoxication, which are also organ-specific and dependent on the age of the animals: a higher level of activity of the inhibitory link and the content of MMM was observed in rats in the puberty period, which leads to a decrease in the potential of the protective mechanisms of the organism and can become a trigger dysfunctional systems of natural detoxification and biotransformation. Inhibition of apoptosis is the main consequence found in the body of experimental rats. This phenomenon can lead to processes that inhibit one of the main mechanisms that reject damaged cells from the population. Females who were in puberty were more susceptible to dietary synthetic estrogens. In contrast to adult animals of the same sex, whose indicators indicate the importance of age characteristics of the body for the ability to perceive the effects of xenoestrogens. Rats became less sensitive to the effects of these substances with age. The difference in experimental animals was due to changes in the rate of detoxification pathway reactions, and not in the metabolism of estrogens entering the body, in particular, with food.

1. Introduction

The destruction of the endocrine system by chemicals, which are a group of compounds that negatively affect the endocrine system, is an urgent problem up day. Such substances are often found in everyday products and are epidemiologically associated with several diseases. Currently, the endocrine system by chemicals (EDCs) data bank contains 1,000 molecules, including pesticides, natural and industrial products, cosmetics, medicines and food additives, and other low-molecular-weight xenobiotics [1]. These environmental estrogens can be categorized into the groups: (1) naturally occurring non-steroidal plant estrogens or phytoestrogens; (2) the steroid estrogens – 17β estradiol and estrone from animal and human sources; (3) the mycotoxins, zearalenone and zearalenol; (4) synthetic compounds with phenolic groups; (5) metalloestrogens, such as, arsenic, cadmium, and manganese [2–4].

The human population is now ubiquitously exposed to countless environmental and stochastic factors such chemicals in daily life, in indoor as well as outdoor environments, through their use in pesticides/herbicides, predatory insects, industrial and household products, plastics, detergents, flame retardants and as ingredients of personal care products, oral contraceptives, hormonal therapy [3, 5, 6]. Intake to the human body may be oral, inhalation or dermal absorption [7, 8]. Estrogens are also used in animal husbandry to increase growth. Both farm and urban sewage effluent contained substantial amounts of steroidal estrogen pollutanted water sources such as surface and groundwater [3, 6, 9–12].

After a while, these pharmaceutical hormones mimic estrogen. Also, there were natural links between endocrine disruptors (EEDs) in the environment and changes in microbial ecology, as well as an increase in the level of resistance of pathogenic organisms to antibiotics, toxicity of the aquatic environment and microorganisms, and a decrease in the resistance of human health [6, 13–19].

The Endocrine Society declares what endocrine disrupting chemicals (EDC) are an exogenous chemical, or mixture of chemicals in the Statement of Principles. They interferes with any aspect of action of hormone" and as an exogenous agent. Ones can be connect with the production, release, transport, metabolism, binding, action or elimination of natural hormones in the body. EDC are responsible for the maintenance of homeostasis and the regulation of developmental processes [2, 13, 20–22].

Metabolic disorders, changes in lactation, breast density, immune function of the body, and other adverse consequences are the result of deterioration of the endocrine system (for example, obesity, changes in the timing of puberty and menopause [5, 23–25].

Some authors have identified signs of multifactorial hormonal activity in several EDCs. For confirmation, we can consider the pesticide DDT, which is an agonist of the endogenous active substance estrogen, and one of its metabolites is antiandrogenic. The research have shown that the estrogenic activity of bisphenol A (BPA) is an antagonist of thyroid hormones. If we take into account the affinity of estrogen (ER) to nuclear receptors , we can determine that xenoestrogens are usually less effective. The effects that occur at low doses are explained by the fact that they act additively with endogenous estrogens. Chemical bonds of xenoestrogens with plasma carrier proteins have significantly lower affinity. In natural estrogens, this affinity is much better, so they are more easily accessible to target organs [2, 26–32].

Some environmental chemicals may be able to interfere in the endocrine regulation of energy metabolism and adipose tissue structure. This includes compounds to which the human population is exposed in daily life through their use in pesticides/herbicides, industrial and household products, plastics, detergents, flame retardants and as ingredients in personal care products. This has the potential for a vicious spiral not only of increasing obesity but also increasing the retention of other lipophilic pollutant chemicals with an even broader range of adverse actions [10, 26, 33, 34].

The metabolomics analysis identified various metabolites that are affected by various estrogen treatments. There are the increased risk of thrombosis, marked changes in the distal tubules and collecting ducts in the kidneys of rats exposed to phthalate, and hypertrophy in the hepatocytes of the centrilobular zone of the liver [2, 17, 35]. Combinations of gene chains directly regulated by ER, such as lipid metabolism, and other gene networks may be responsible for such changes. Gene networks are activated in response to disruption of physiological liver processes, such as pathways associated with oxidative stress [2, 24, 36].

Exposure to estrogens is associated with increased risk of breast and other types of human cancer [30, 37, 38]. Environmental EDS ligands represent an emerging threat to human bone health [39]. Brain cells and neural circuits are likely to be influenced by estrogenic endocrine disruptors (EEDs) because they strongly dependent on estrogens [1, 8, 40, 41].

Age and/or estrogenic surroundings affected the difference in effects [42]. A process known as developmental reprogramming can permanently reprogram normal physiological responses under the influence of changing environmental conditions. Such changes in physiological responses increase the body's susceptibility to diseases later in life [1, 43, 44].

It is very difficult to develop clear clinical guidelines to address the potential health effects of toxicants that are commonly seen at all levels of the organization among the general population. The lack of a complete understanding of the main mechanisms of exposure to toxicants entering the environment and the level of their impact on a living organism significantly complicates scientific research on this issue. [2, 23, 45].

Proteolysis is an important component of the homeostasis of the body, which serves as a trigger mechanism for many biological processes, maintains a dynamic equilibrium in hemostasis and affects the function of membrane cells. Proteases are involved in the processes of programmed cell death due to selective release of lysosomes in response to various effects [46,47].

The aim of the study was determination of the effect of xenoestrogens on the proteolytic processes of different age rats.

2. Materials and methods

The experiments were conducted on Wistar rats exposed to exogenous estrogen for 45 days. At the beginning of the experiment 3-month-old pubertal animals (group II) and 6-month-old sexually mature rats (group IV) were involved. The control group consisted of intact appropriate age animals (groups I and III). For modeling exogenous estrogen impact rat' meal is treated with the drug "Synestrol" as stilbene derivative differing from steroid hormones estrogen on chemical structure, but by biological and medicinal properties similar to them in the rate of 2 mg per kg. The research materials were organ tissue and blood serum of the rats. The objects were indexes of activity of trypsin and its obligatory inhibitors $\alpha1$ - antitrypsin ($\alpha1$-AT) and $\alpha2$-macroglobulin ($\alpha2$-MG) [47], cysteine cathepsins B and L [48], integrated indicators of endogenous intoxication syndrome (EI), namely, the molecules of middle mass (MMM) level [49]. The data were treated with standard methods of variation series estimation. The difference between the comparative values was considered probable at $p < 0.05$.

3. Results and discussion

Cysteine cathepsins are important regulators and signaling molecules of many biological processes. Cathepsins B and L are expressed in all tissues of the body and play an important role in the physiological intracellular degradation of proteins. The enzymes are involved in the development of a number of pathological conditions [50]. Cathepsins B and L carry out regulatory action, post-synthetic modification of precursors of peptide hormones and neurotransmitters [50]. Trypsin is secreted by the pancreas in the form of an inactive precursor – trypsinogen. Transformation of zymogen into trypsin occurs more intensively under the influence of cathepsin B, while cathepsin L inactivates trypsin [51].

After conducting research on the determination of the effect of exoestrogen on the proteolytic processes of pubertal and sexually mature females rats the following results were obtained.

For example, the role of genotoxic carcinogens with estrogenic activity formed during meat roasting, on the induction of colon, prostate and mammary gland, is assumed to be influenced by expression in nanomolar concentrations on the expression and activity of matrix proteinases, and in particular, of cathepsins, which mechanically supports tissue-specific carcinogenicity of the like substances caused invasion of tumor cells through the basement membrane [52, 53].

The activity of cysteine cathepsin L was reduced by 15 % in the liver of pubertal females when compared with control and 10 % at the sexually mature individuals of group IV. Cathepsin B was activated by 30 %, respectively (table 1).

Trypsin has been shown to be a nonspecific carrier of steroid hormones, as well as proteolytic cleavage of estrogen receptors [53]. The increase of trypsin index in the experimental group II of rats (by 12 %) was observed in the liver, while in the mature female the enzyme activity was increased by 7,5 % in the IV group (table 1).

Table 1. Proteolytic indices of different age female rats exposed to alimentary estrogens.

Index	I group	II group	III group	IV group
		Liver		
Trypsin, nmol/sek/g protein	0,65+0,03	0,73+0,04*	0,67+0,033	0,72+0,036*
α1-AT, µmol/ sek/g protein	0,46+0,02	0,54+0,03*	0,48+0,024	0,53+0,027*
α2-MG, µmol/ sek/g protein	0,24+0,02	0,22+0,02	0,24 +0,01	0,25+0,01
Cathepsin L, units./ g protein	21,19+1,06	18,01+0,91	20,78+1,04	18,65+0,93
Cathepsin B, units/ g protein	20,88+1,04	27,06+1,05	21,07+1,05	25,34+1,05
MMM, units	8,78+ 0,44	9,83+0,52*	7,68+0,38	8,22+ 0,44
		Brain		
Trypsin, nmol/sek/g protein	0,061+0,004	0,073+0,003*	0,067+0,003	0,072+0,003*
α1-AT, µmol/ sek/g protein	0,25+0,01	0,29+0,01	0,24+0,01	0,26+0,01
α2-MG, µmol/ sek/g protein	0,14+0,01	0,22+0,01*	0,15 +0,02	0,17+0,02
Cathepsin L, units./ g protein	12,74+0,61	13,66+0,68	11,05+0,55	12,48+0,72*
Cathepsin B, units/ g protein	14,07+0,73	15,47+0,77	14,25+0,70	13,11+0,66
MMM, units	4,67+0,23	5,42+0,19*	4,15+0,22	4,73+0,23*
		Kidneys		
Trypsin, nmol/sek/g protein	0,59+0,04	0,67+0,03*	0,62+0,03	0,67+0,05*
α1-AT, µmol/ sek/g protein	0,32+0,02	0,345+0,02	0,34+0,02	0,35+0,02
α2-MG, µmol/ sek/g protein	0,18 +0,01	0,21+0,01*	0,19+0,01	0,20+0,01
Cathepsin L, units./ g protein	15,47+0,77	15,62+0,78	16,03+0,8	16,42+0,72
Cathepsin B,units/ g protein	10,55+0,67	16,47+0,53*	12,17+0,69	15,76+0,66*
MMM, units	8,37+1,42	11,09+1,74*	8,41+1,42	9,34 +1,58*
		Blood serum		
Trypsin, nmol/sek/g protein	1,20+0,09	1,73+0,12*	1,25+0,12	1,54+0,16*
α1-AT, µmol/ sek/g protein	0,15+0,01	0,17+0,02*	0,17+0,01	0,19+0,12
α2-MG, µmol/ sek/g protein	0,014+0,001	0,015+0,001	0,012+0,001	0,014+0,002
Cathepsin L, units./ g protein	1,21+0,14	1,39+0,09*	1,16+0,11	1,24+0,10*
Cathepsin B,units/ g protein	1,17+0,13	1,69+0,11*	1,11+0,17	1,42+0,11*
MMM, units	6,23+0,26	7,38+0,92*	6,74+0,38	7,68+0,62*

Note: * - difference between the index of experimental group to intact appropriate age rats index is considered probable at $p<0.05$

Proteolytic inhibitors perform important physiological functions: delay the premature activation of proteolytic enzymes, protect proteolytic tissue from microbial enzymes, regulate the state of the coagulation system and fibrinolysis, affect arterial pressure and vascular permeability, apoptosis processes. The ratio of systems with mutually opposite action is in a strictly dynamic equilibrium, where each of them has a significant role in the regulation of the vital activity of the organism [54]. For the excess of trypsin, the distribution of the enzyme between the two major inhibitors α1-antitrypsin (α1-AT) and α2-macroglobulin (α2-MG) occurs according to their molar content. The index of alpha-1-antitrypsin increases with inflammatory processes, such as acute, subacute and chronic infectious diseases, acute hepatitis and cirrhosis of the liver in active form, necrotic processes, post-operative conditions, Alpha-2 macroglobulin is a glycoprotein, an inhibitor of plasma proteinases, and is used as a marker for cell membrane permeability. α2-MG level increase can be observed in various pathological conditions, such as nephrotic syndrome, hormonal dysfunctions or disorders associated with the development of the child's body. α2-MG suppresses the activity of leukocyte and synovial collagenases, cathepsin B, calicreatin plasma [4].

The level of α1-AT was higher in group II by 17 % when compared with intact rats and dominated in group IV (by 11 %). Due to the positive effect of estrogens on the synthesis of α2-MG, its concentration in women is approximately 20 % higher than that of men. α2-MG has the ability to bind hormones and cytokines (IL, IFN, TNF-a, growth factors) [55]. The activity of α2-MG tended to decrease in the experimental rats of pubertal age and weakened in the experimental sexually mature individuals (table 1).

Exposure of the drug Synestrol in the brain of the rat in the pubertal period has been shown to activate cathepsin B by 10 % compared with the control group of the same age. In the sexually mature female, the activity of the enzyme in the experimental group is reduced by 8%.

Nerve cells contain large amounts of cathepsin L [56]. A cathepsin L function in secretory vesicles is defined as a key protease for the proteolytic processing of proneuropeptides and prohormones in active neuropeptides, which are mediators for synapses in intercellular communications in the nervous system. During the exposure of the Synestrol drug in the rat brain, both subjects underwent cathepsin L activation: 7 % (group II) and 13 % (group IV).

In determining of trypsin activity it was found that in the experimental group I the enzyme activation was dominant over the indicator of the corresponding control group by 20 $^0/$ in the brain. In the experimental group of sexually mature individuals, trypsin activity was 7,5 $^0/$ higher than in female experimental group. There was a tendency to increase of α1-AT enzymatic activity in the experimental groups of pubertal and mature females by 16 % and 8 %, respectively. In the study of α2-MG activity, the deterministic activation was 57 % in the experimental group II, while the deviation of the index between experimental groups of adult-raised animals was 13 % (table 1).

Widespread expose of estrogens has led to the need for studies of biochemical changes in the kidneys. According to the results of studies of shifts in the proteolytic system, it has been found that trypsin activity increased by almost 14 % in the kidneys of puberty female and 8 % in adult individuals. No significant differences were found for the α1-AT index between groups III and IV, for group II, growth was 8 %. A similar trend of change is characteristic for α2-MG: the activation was 5 % and 17 %, respectively (table 1).

According to the references, the assessment of the long-term effects of estrogen on lysosomal enzymes such as cathepsins B and L has shown changes in the activity of enzymes that were more significant at low doses of estrogens: there was no correlation between doses and the activity of lysosomal enzymes [12].

For females of the younger group, the kidney activity of cathepsin B exceeded the control values by 57 %, in older rats - by 29,5 %. There were no differences in the activity of cathepsin L between the experimental and the corresponding control groups. It has been established that the alimentary exposition of estrogens leads to the activation of the proteolytic chain in the study of serum. Thus, for females under the age of 4,5 months, trypsin activation was 44 %, cathepsin B – 44 %, cathepsin L – 15 %. For females aged 7,5 months, activation was 23 $^0/$, 23 % and 7 %, respectively. The reaction of the serum inhibitor in the group II females was 13 % (α1-AT) and 7 % (α2-MG), group IV – 12 % and 17 %, respectively (table 1).

Endogenous intoxication (EI) is a clinical syndrome that arises at various etiology pathological conditions due to the accumulation in tissues and biological fluids of the body of the metabolic, destructive cell and tissue structures, destroyed protein molecules, accompanied by functional and morphological lesions of organs and body systems. There is a direct correlation between the level of proteolytic activity of the blood with integrated indicators of endogenous intoxication syndrome (EI), namely, the molecules of middle mass (MMM) that can inhibit transformation of lymphocytes, phagocytic activity of leukocytes, cause neurotoxic action and disjunctive effect on processes of tissue respiration and oxidative phosphorylation, inhibit protein synthesis in the non-cellular systems, promote hemolysis of erythrocytes, influence erythropoiesis, sharply disturb the permeability of membranes and cause cellular aggregation. The accumulation of toxic metabolites also contributes to limited proteolysis reactions catalyzed by lysosomal enzymes in the intercellular space, which leads to damage both at the cellular and organ levels [57].

The imbalance in the proteolytic system leads to excessive formation of the peptides (medium molecules) with toxic properties. It has been shown their accumulations in the organs of rats of both experimental groups. Thus, the increase in the content of MMM in female pubertal females consumed Synestrol was 12 % in the liver, 32,5 % in the kidneys, 18,5 % in the blood serum, and 16 % in the cerebrum. In mature females, the increase was 7 %, 11 %, 14 % and 14 %, respectively.

In summary, the eating food contaminated by exoestrogens led to changes in the proteolytic system and the development of endogenous intoxication. A higher level of the inhibitory link activity and the content of MMM were observed in rats in the puberty period, which leads to a decrease in the potential of the protective mechanisms of the organism and can become a trigger of dysfunction systems of natural detoxification and biotransformation. Females were more exposed to dietary synthetic estrogens during puberty than adult animals. Such data prove that age is also a factor in the influence of xenoestrogens on processes in the body. Animals became less sensitive to the effects of these substances with age. This reaction is explained by changes in the rate of detoxification processes, and is not associated with the metabolism of estrogens entering the body, in particular, with food.

Considering the state of processes of proteolysis in the organs of females using xenoestrogens, it is possible to admit of reconstructing of the mediator functioning possibility and enzyme systems, additional enhancement of pathological symptoms. It's assume the above effects can initiate endocrine disruptions, simulate responses depended on steroid hormones receptors, as well as receptor-independent processes in the pathological, namely, promote increased proliferative activity, inhibition of apoptosis, stimulation of neoangiogenesis, cause changes in the epithelium of the organs that affect on the metabolic process, and to be trigger mechanisms for the development of carcinogenesis in hormone-dependent organs, in particular, the mammary gland, formation of general pathological state in the organism. Explaining the effective mechanisms of proteolytic processes will help clarify the importance of risks in environmental changes for an organism with different age indicators. Also, a deeper analysis will provide evidence to reduce the impact of negative factors and, ultimately, reduce the burden of age-related diseases.

4. Conclusions

Thus, the alimentary exposition of rats with exoestrogens leads to changes in the proteolytic system and the development of endogenous intoxication, which are organ-specific and age-dependent animals. The control difference of signs in an organism provides various influence on the following types of interaction, namely a cell - a cell, a cell - an extracellular matrix. In addition, soluble factors can be a trigger for disruption of information transmission by signaling pathways. We believe that the identified phenomena may lead to the suppression of one of the main mechanisms of removal of damaged cells from the population, namely apoptosis.

The observed effects were more expressed in females during puberty than in mature rats. The obtained results prove high sensitivity of living organisms to exogenous estrogen-like compounds at specific age-related physiological conditions.

Our conclusions prove the need for a comprehensive study to determine the trigger role of xenoestrogens contained in food in the development of pathological changes in the body. The information obtained can be a paradigm for risk assessment and prevention of diseases, the etiology of which is the alimentary intake of xenoestrogens.

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A computer simulation of population reproduction rate on the basis of their mathematical models

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A computer simulation of population reproduction rate on the basis of their mathematical models

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Abstract. The article deals with the adoption of computer modeling as one of the leading areas of introduction of modern information technology in the modernization of content, forms and methods of teaching. In order to implement interdisciplinary integrated learning, the possibilities of interdisciplinary integration of learning content have been identified, the practice of using software environments in the process of modeling biological problems based on mathematical models has been analyzed, the possibilities of implementing algorithms of mathematical models in computer modeling have been investigated. A set of research tasks in biology as a basis for the implementation of interdisciplinary integration: nature - mathematics - computer science has been introduced into the educational process. The mathematical models of Verhulst, Arim, Leslie and the exponential law of direct proportional dependence or proportional rate of reproduction depending on the number of individuals of a population were used to design computer models of reproduction of ecological processes. They were implemented using the computer mathematics system MathCad and using programming environments Python, C♯, C++. The expediency of the proposed method of interdisciplinary integration of learning content has been justified through a developmental and productive integrated approach, the use of certain collective forms of activity, the practical orientation of professional training disciplines to form algorithmic competence of students as a basis for professional competence in computer modeling of mathematical models of biological processes.

1. Introduction

1.1. Formulation of the problem

Many talented young people who have a high level of knowledge in fundamental disciplines and successfully study computer technologies and software study in educational institutions of Ukraine. It is very important to single out such creative personalities in general, to consider their abilities, to help master creative thinking skills – to model and generate original ideas, to make informed decisions based on the use of mathematical methods in combination with modern information and communication technologies (ICT).

Today, education focuses on the widespread introduction of ICT and involves the modernization of content, forms and methods of teaching, there is already a steady trend to adopt computer modeling as one of the leading areas in research in various areas, including modeling of biological systems. “The logical basis for studying the phenomenon is the inference from general to partial. It allows the student in the process of developing a hypothesis and its solution to move from the already known general provisions of science and laws to the problem posed in the task” [1].

The term ‘task’ is defined as a set of actions designed to perform. In the scientific literature there is no unambiguous approach to the definition of ‘research task’, because the research task contains a problem that requires theoretical analysis, the use of one or more research methods with the help of which students can discover previously unknown knowledge [2].

The researched tasks have an integrative character which assumes besides knowledge of the field of modeling also use of the mathematical device, and it in turn, is the basis for computer modeling. Computer modeling in the context of our research is a way to solve problems. The tasks, in turn, precede computer simulation.

Designing tasks for computer modeling of biological processes based on their mathematical models requires an analysis of the development of opportunities for the use of ICT in modeling processes in various industries. The relevance of computer modeling is evidenced by numerous publications that are increasingly appearing in leading scientific and methodological publications in recent years.

Analysis of recent research and publications. General issues of computer modeling have been considered by such scientists as A. H. Balakireva [3], Yu. O. Zhuk [4], N. R. Balyk [5], S. O. Solovyov [6], I. O. Teplytskyi [7], etc. Modeling of pedagogical phenomena with the use of artificial intelligence is revealed in the works of B. B. Buyak [8], H. V. Tereshchuk, I. M. Tsidylo [9], etc.

A number of researchers have studied the peculiarities of application of computer simulation technologies. Santo Motta, Francesco Pappalardo – mathematical modeling of biological systems [10]. Zhiwei Ji et al. – mathematical and computational modeling in complex biological systems [11]. Hans Peter Fischer – mathematical modeling of complex biological systems [12]. David Gavaghan et al. – mathematical models in physiology [13]. Mark A. J. Chaplain – multiscale mathematical modelling in biology and medicine [14]. Peter Kohl et al. – computational modelling of biological systems: tools and visions [15]. Steven H. Wiley et al. – computational modeling of the EGF-receptor system: a paradigm for systems biology.

Integration is a general and multifaceted process of establishing links between information, knowledge, science, and ensuring their integrity and unified structure. One of the most important [16]. Vlyssides A., S. Mai and E. M. Barampouti – an integrated mathematical model for co-composting of agricultural solid wastes with industrial wastewater [17].

The use of the modeling method in the training of future specialists is presented in the works of S. V. Kozibroda [18], S. H. Lytvynova [2], Yu. O. Zhuk [19] and others.

In the monograph [6] the authors determine the conditions of professional training of future teachers of natural sciences and mathematics by means of computer modeling; a structural and functional model of training has been developed; socio-constructivist forms of organization, methods and tools for teaching computer modeling of future teachers of natural sciences and mathematics have been selected. “The main common feature of natural sciences, the foundations of which are laid in the content of education in natural sciences and mathematics, is the leading research method used in them – modeling, which in the learning process becomes a system-forming component of the content of education. Given that in computer science as a science and academic discipline, the method of modeling is also a leading method of research and teaching, in the process of teaching students of natural, physical, mathematical and computer science specialties of pedagogical universities it is necessary to master both computer modeling technology and teaching technology as research based on object-oriented approach to modeling and social-constructivist approach to learning”.

New computer models unify ecological theory: computer simulations show that many ecological patterns can be explained by interactions among individual organisms [20].

The method of mathematical and, consequently, computer modeling is one of the forms of interdisciplinary activities that allows to integrate knowledge and activities from different fields of science, which greatly contributes to the development of research competence of students [21].

Mathematical and computer modeling contributes to the discovery, preservation and development of personal qualities of students. However, their use in the educational process will be effective only if a correct idea of the place and role of computer modeling in the educational process is formed [22, p. 9].

O. I. Teplytskyi expressed his opinion on the model of training future teachers of natural sciences and mathematics by means of computer modeling at the VI All-Ukrainian scientific-methodical seminar "Computer modeling in education". The future teacher must have the technology to design their own professional activities, be able to develop and apply innovative pedagogical technologies. In this regard, special attention in developing a model for training future teachers of natural sciences and mathematics was paid, on the one hand, to promising areas of development of educational systems (technological aspect), and on the other hand to the integration basics of teaching physics, mathematics, chemistry, biology, geography and computer science (fundamental aspect). Under this approach: 1) the subject of study becomes not just a student, but is formed and developed by a specialist, and the accumulated potential provides progressive self-development of professional competence in a modeled, simulated or real professional activity; 2) the student in the integrative course masters social-constructivist technologies of transformation of the content of training into ways of professional activity in fast-changing conditions [7].

Given the dynamic development of ICT, the diversity of methodological approaches, methods of using computer modeling systems to create projects for various research tasks and training of young people, such issues require additional research, refinements, approaches, models, developments, and new implementation methods.

The purpose of the article is to demonstrate the interdisciplinary integration of learning content through the theoretical substantiation of the technology of studying mathematical models of ecological systems using computer mathematics systems and programming languages.

2. Theoretical foundations of the study

To train specialists of a certain profile, it is advisable to use tools that develop skills and abilities, promote the development of design and research activities. Nowadays, the most promising method is STEM-education, because it is the integration of certain disciplines into a single system of education that has proved extremely effective. Built on interdisciplinary and applied approaches, STEM-education provides a mixed (interdisciplinary) educational environment in which students acquire theoretical knowledge and practical skills in the application of scientific methods of cognition. Today, the technology of integrated learning has become a leader in higher education institutions of Ukraine.

In the process of learning about the world, humanity widely uses a variety of models. Modeling is a universal method of scientific knowledge based on the construction, research and use of models of objects and phenomena. The most important type of modeling is mathematical models [23]. Along with the traditional areas of use of mathematics, new disciplines are increasingly involved in its scope of use.

Mathematical modeling involves the ability to program, actively use knowledge of natural sciences and their subsequent application in various fields of human activity to obtain new knowledge. The problem cannot be solved only by remembering the ready-made knowledge, it is necessary to think, look for connections and relationships, and select evidence [24]. Research tasks are not new, but the method of their consideration is still insufficiently studied, due to the high complexity of experiments, which are an integral part of the study [4].

Integration is a general and multifaceted process of establishing links between information, knowledge, science, and ensuring their integrity and unified structure. One of the most important aspects of integration in education, without a doubt, is the purposeful integration, synthesis of relevant educational components into an independent system of purpose, which aims to ensure the integrity of knowledge and skills of students.

The integration of educational components takes place in several areas and at different levels of higher education. In our study, we use internal disciplinary integration [25], which is carried out in the process of preparing a student of the first (bachelor's) level of higher education, involves a fragmentary process carried out at the level of each discipline and involves the search of interaction of different elements within the educational component and new approaches for the formation of students' ability to integrate computer modeling and mathematical models.

As we can see, the education of modern bachelors is component-centric, which is why the main focus here is on the internal integration of the content of educational material. The transition of education to a qualitatively new level is, in essence, a movement from intra-component to inter-component integration of learning content. This process is most clearly observed at the second (master's) level of higher education, namely in the process of writing a master's thesis using computer simulation.

3. Research methods and tools

The introduction of interdisciplinary integrated learning in the educational process allowed us to set the following tasks: 1) to trace the possibility of interdisciplinary integration of learning content; 2) to investigate the practice of using software environments in the process of modeling biological problems on the basis of mathematical models; 3) to investigate the integration of algorithms of mathematical models in the process of computer modeling.

The following theoretical and experimental research methods were used to solve the tasks: analysis of scientific, educational and methodological literature, search for modeling methods, analysis of applied mathematical packages and programming environments for the implementation of the created model; methods of mathematical modeling, time series analysis, regression analysis, methods of algorithmization and programming were used; analysis of the obtained results in accordance with the research problem, experiment (ascertaining, searching and forming) with the subsequent statistical processing of the results.

One of the conditions for the success of the introduction of integrated learning in the educational process is the use of information and communication technologies in the educational process, the teacher's knowledge of the functionality of modern digital technologies, and his/her practical skills to work with them [26].

When modeling environmental processes, programming languages (Python, C♯, C++) and ready-made software products (MathCad, MATLAB, Matematika, Microsoft Office software package, etc.) were used. Digital technologies can be used at all stages of preparation and execution of the modeling process. They do not replace the teacher, but only expand his/her capabilities.

One of the dangers of environmental modeling is the uncertainty of the models and the lack of supporting data. Only with the correct use of the model is it possible to study a wide range of uncertainties, indicating the limits of current knowledge and identifying critical information needed for management decisions. However, it is impractical to rely entirely on the conclusions of any model.

The integration processes proposed by us were carried out with the use of collaborative learning technology, namely, by involving the practice of interaction of participants in the educational process (students of bachelor's degree in chemical-biological, physical-mathematical and engineering-pedagogical faculties of Ternopil Volodymyr Hnatiuk National Pedagogical University), which allowed them to develop skills to work together in a small group and ensure quality educational outcomes [27].

The material for the study was a collection of red fistula, started by students of the Faculty of Chemistry and Biology during training in zoology in during 2017 and 2019. In total, students collected more than 1,000 specimens of the species. Partnership between undergraduates of the first year of study of chemical-biological, physical-mathematical and engineering-pedagogical faculties began in 2020 at the stage of processing the collected material.

4. The results of the study

The process of interdisciplinary integration of learning content was carried out by us by applying a number of mathematical models to the study of ecological systems using computer mathematics systems and programming environments, on the basis of which it was possible to implement specialized research.

Work began on modeling the dynamics of fluctuations in biomass and productivity of the population of grape snail (Helix pomatia), which has been consumed for centuries by residents of a number of European countries. Recently, intensive collection and procurement of mollusks for export abroad and for own use have begun in various regions of Western Ukraine. Uncontrolled collection of these animals can lead to the destruction of natural populations of Helix pomatia and, as a consequence, disruption of the cycle of substances in the ecosystems of the region. The task of studying the population growth dynamics was formed for students of two faculties who studied according to individual plans. Free schedule, consultations with teachers, and search on the Internet allowed them to successfully cope with this task.

The material was collected in the forests around the village of Velyki Chornokintsi, Chortkiv district, Ternopil region, during the spring-summer-autumn periods. Numerical modeling was carried out on the basis of two equations:

1) equation for calculating the population growth rate

$$V_n = rN - \frac{r}{k}N^2, r = \frac{\ln(N_2) - \ln(N_1)}{t_1 - t_2} \tag{1}$$

2) equation for calculating the maximum possible biomass

$$N(t) = N_0 e^{r(t-t_0)} \tag{2}$$

The predicted figures were obtained using the C♯ programming system. In order to verify the correctness of the solution to this problem using Microsoft Visual Studio C♯ 2010, a computer model was built in the Mathcad environment (figure 1).

The verification of the developed model was carried out according to the monitoring data of this population, which were obtained by students of the Faculty of Chemistry and Biology during the spring-summer-autumn training practices.

The analysis of the obtained results allowed us to draw conclusions about the adequacy of the selection of the mathematical functional by using which we obtained a solution. Both developed computer models obtained the same results [27].

The most available integrated characteristic of animal and plant populations is abundance, which is closely related to many other biota parameters. Therefore, traditionally in theoretical and practical ecology, the study of population dynamics is given paramount importance. However, many aspects of population estimation and analysis still remain controversial.

That is why under the condition of constant monitoring of the state of development and dynamics of changes and control over the rate of withdrawal of individuals from the population, as well as under the correct forecast, the population can exist indefinitely and maintain its productivity.

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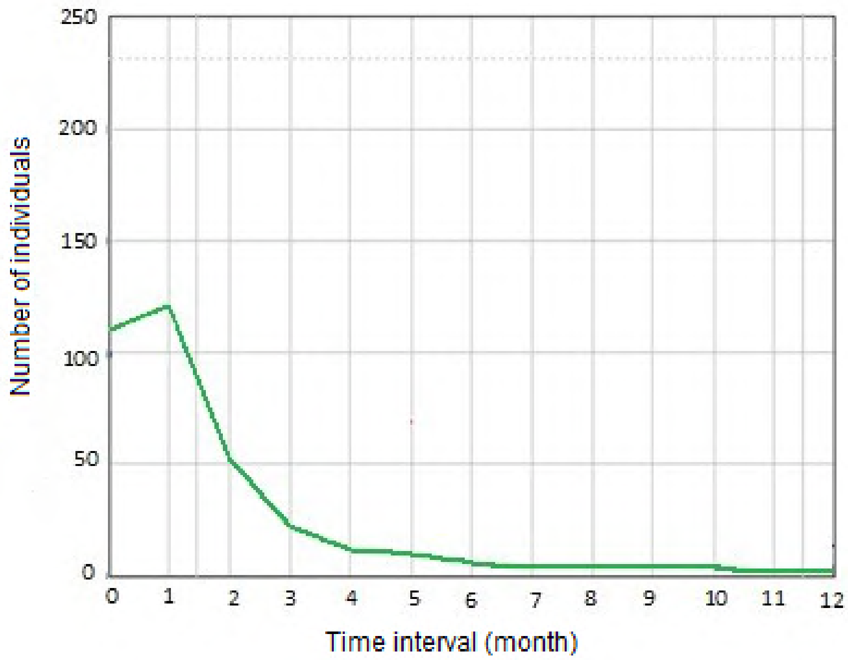

Figure 1. Model of population dynamics in a given area.

To date, there are many models for predicting time series: regression and auto-regressive models, neural network models, models of exponential smoothing, models based on Markov chains, classification models and others. Each of the existing models has advantages and disadvantages that can be significantly reduced by choosing the right field of application. It has been determined that the most promising direction of development of forecasting models in order to increase accuracy is the creation of combined and modified models.

Therefore, the next step was to use the ARIMA model [1] to predict the number of individual biological populations. Masters of physics-mathematics and chemistry-biology faculties were involved in the cooperation, who analyzed more than 40 models and created a modified autoregressive forecasting model, which has a higher efficiency of forecasting different time series compared to other models. A new method of forecasting was developed on the basis of the proposed model and software implementation of algorithms was performed; the efficiency of the offered forecasting model in solving the problem of forecasting of population time series has been estimated. The results of research in master's theses aroused great interest of specialists in this field.

The essence of building an Arim model for predicting population dynamics. Suppose there is a population in a certain environment. We will not impose restrictions on the area of location of individuals. Environmental monitoring has been conducted for a long time, as a result of which data on the number of specimens of the population in the specified time intervals have been collected. It is important that the recording of monitoring results was carried out with a given period, in our case – annually.

When constructing a graph based on the obtained data, you can see some explicit patterns (figure 2).

The time series has an obvious seasonality and an uncertain general trend to increase or decrease (figure 3).

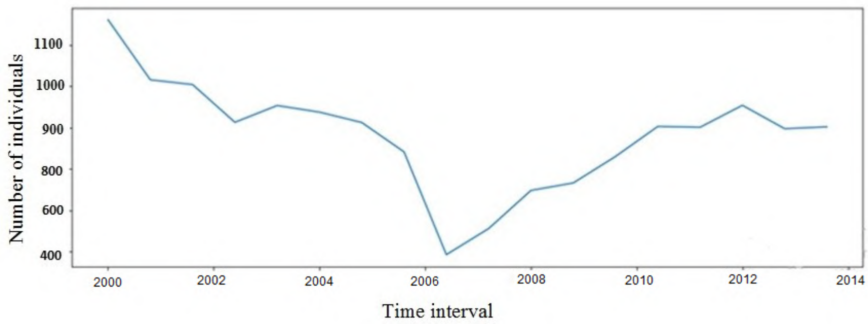

Figure 2. Annual readings of the number of individuals in the population.

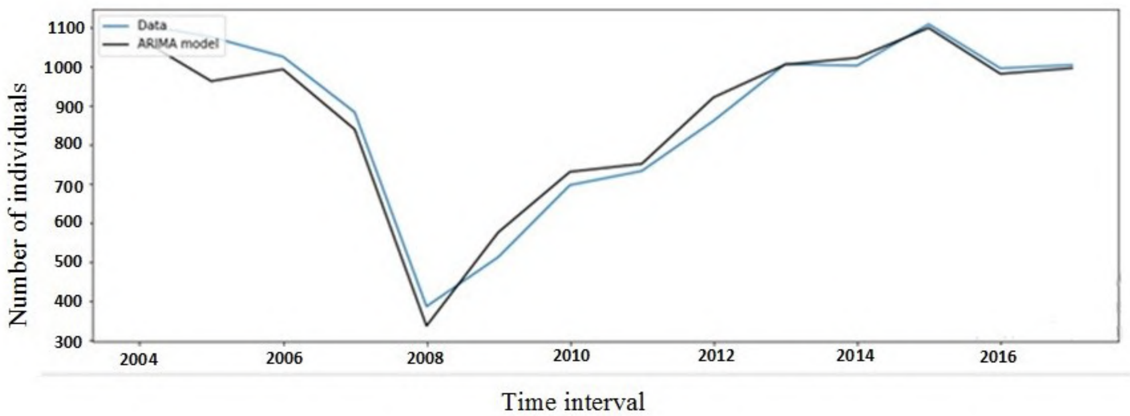

Figure 3. Checking the accuracy of the constructed model.

The construction of the model was based on the equation:

$$\triangle Dy_t = \sum_{i=1}^{n} \phi_i \triangle Dy_{t-i} + \sum_{j=1}^{q} \theta_j \epsilon_{t-j} + \epsilon_t, \epsilon_t \sim N(0, \sigma^2) \quad (3)$$

The resulting forecast can be seen in figure 4.

The implementation of the proposed forecasting model using the Python programming language showed high accuracy of time series forecasting, which allowed to build a forecast for 2018 - 2025 to determine the future values of the population. The developed forecasting method based on the ARIMA model is implemented in the form of a software application that performs population forecasting based on annual monitoring data [27].

Equally interesting was the study related to the forecast of individual population development in the framework of the Verhulst model. The model was built on the basis of the Verhulst equation using the knowledge of the ecology of the species. The forecast of population development for several years was calculated and the effect of population composition stabilization within this model was studied. The work was performed by a student of the Faculty of Engineering and Pedagogy in the framework of student research and submitted to the competition.

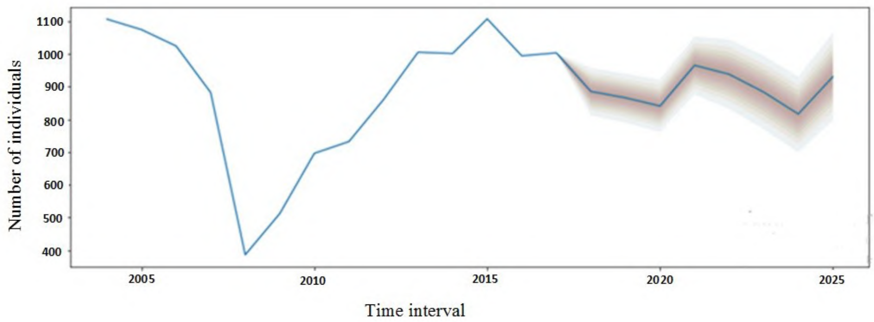

Figure 4. Forecast for 2018 - 2025.

Verhulst's idea [28] was to superimpose on exponential growth, expressed by the formula, some factor that characterizes the slowdown, increasing with population growth. The simplest possible assumption is that the degree of growth retardation for one individual is proportional to the size of the population, that is, the resulting growth rate is not r, but $r(1-\frac{N}{K})$, and determines the growth retardation. In this case, the logistic differential equation will take the following form

$$\frac{dN}{dt} = rN - \frac{rN^2}{K} = rN(1-\frac{N}{K}) \tag{4}$$

and its solution is expressed by the formula

$$N(t) = \frac{N_0 K e^n}{K - N_0 + N_0 e^n} = \frac{K}{1+(\frac{K}{N_0}-1)e^{-n}} \tag{5}$$

The distribution of the growth rate over the territory will be determined according to the formula

$$r(t)_i = \left[\left(\frac{Nf(t)_i}{N(t)_i} * 1,01\right) - D(t)_i\right] \tag{6}$$

where $Nf(t)_i$ is the birth rate distribution, $N(t)_i$ is the overall distribution, and $D(t)_i$ is the population mortality rate.

Estimation of the size of the selected population is presented in figure 5.

We were also extremely interested in research in the field of mathematical modeling done by Balakireva O. G., which were associated with the application of the Leslie's matrix model to ecological systems [3]. The problem was set in front of bachelor students studying computer modeling. The task was facilitated by the fact that the teachers presented an algorithm for solving this problem and theoretical development of the algorithm.

The study of population dynamics is associated with the construction of different population models, these models are often empirical and require additional justification or selection of unknown parameters. Mathematical models of the theory of population ecology can be divided into two groups: continuous and discrete. In continuous models, the number or population density of a population is considered to be a continuous function of time and spatial coordinates. Continuous models usually have the form of one or more differential equations. In reality, the population size is a discrete quantity that acquires certain values at fixed points in time. Discrete population values can be obtained from experimental data (laboratory or field) at discrete points in time. Meanwhile, the task of describing population dynamics leads to the analysis of a discrete system. Most discrete models of population dynamics describe only the change in the total population size (Malthus model, Verhulst model, Reeker model, etc.), without making

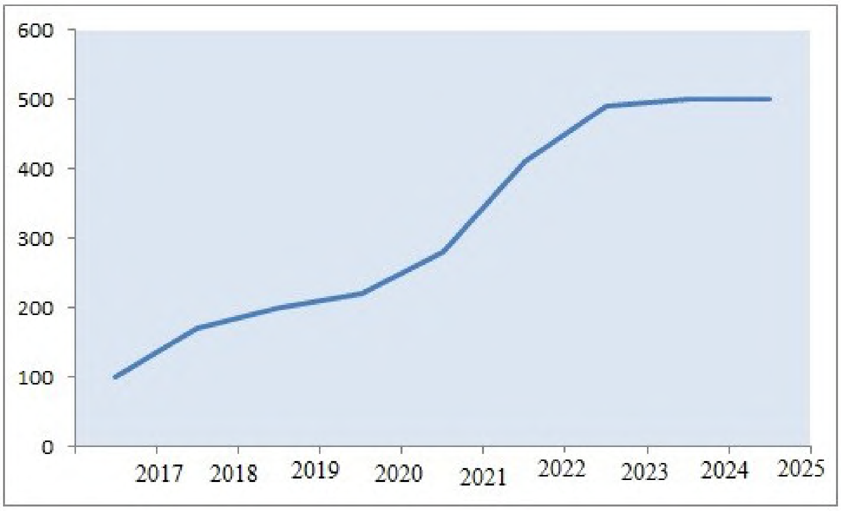

Figure 5. Estimation of the population of beetles from 2005 to 2021 according to accounting data and using the model.

any assumptions about the dependence of mortality and birth rate on the age of individuals. However, in many cases, taking into account the age structure of the population is of great importance.

Simple postulates about the relationship between the number of age groups lead to the socalled classical Leslie model, in which there is no change in the biological parameters of the population over time. But it is known that in practice these parameters change under the influence of climatic conditions, limited food resources and other environmental factors.

The essence of the model. Let the population contain n age groups. At each fixed point in time (for example, t0) the population can be characterized by a column vector

$$X(t_0) = [x_1(t_0), x_2(t_0), ..., x_n(t_0),]^T \tag{7}$$

where $x_i(t_j)$ is the number of individuals in the i-th age group. Survival and fertility rates change at each step.

Leslie's inhomogeneous model for predicting population development over time has the following form: $X(t_n) = L_{0,n}X(t_0), L_{0,n} = L_1 * L_2 * ... * L_n, n = 1, 2, ...$ where L_i is the Leslie matrix in the i-th step

$$L = \begin{bmatrix} 0 & 0 & 0 & 0 & \alpha_k & \alpha_{k-1} & 0 & 0 \\ \beta_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \beta_2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \beta_{n-1} & 0 \end{bmatrix} \tag{8}$$

In the first strip of this matrix there are birth rates, and the survival rates are under the diagonal.

The object of the study was the dynamics of the number of populations of red vole (Myodes glareolus Schreber, 1780; = Clethrionomys glareolus auct.). The study is based on experimental data obtained during 2017-2019. The software implementation of the computer model for predicting the number of population dynamics was carried out by us on the basis of the Leslie model [29].

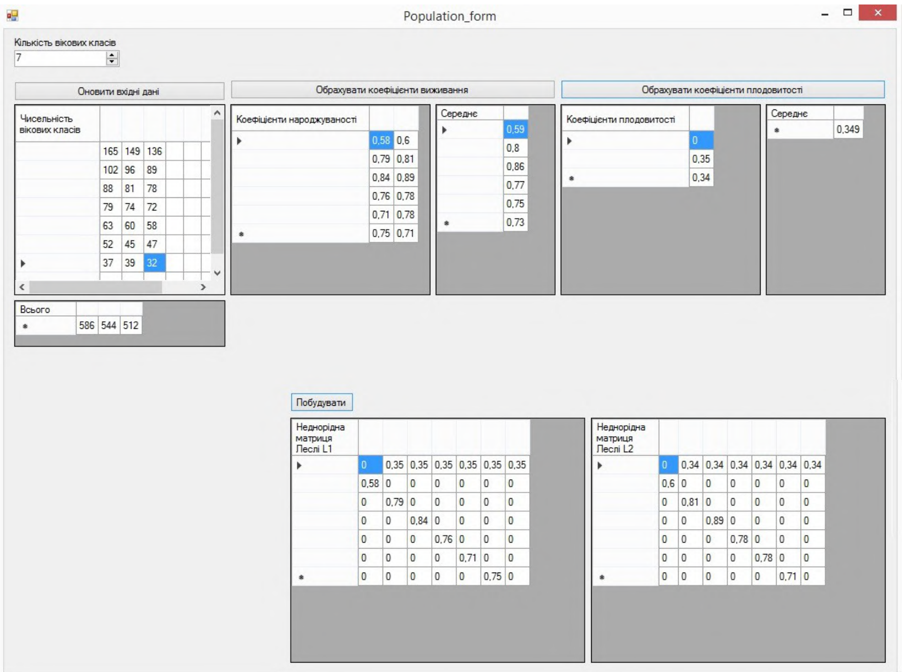

Figure 6. The form of the created application.

The graphical user interface (GUI) of the created application can be viewed in figure 6.

If all elements of the matrix are constants, then, depending on the eigenvalue λ, one of the three scenarios of population development is possible.

If $\lambda < 1$, then the population size decreases. If $\lambda = 1$, then the population size, starting from some point in time, will become constant; if $\lambda > 1$, then the population number will increase. We have $\lambda = 1.683$, so the population number increases (figure 7).

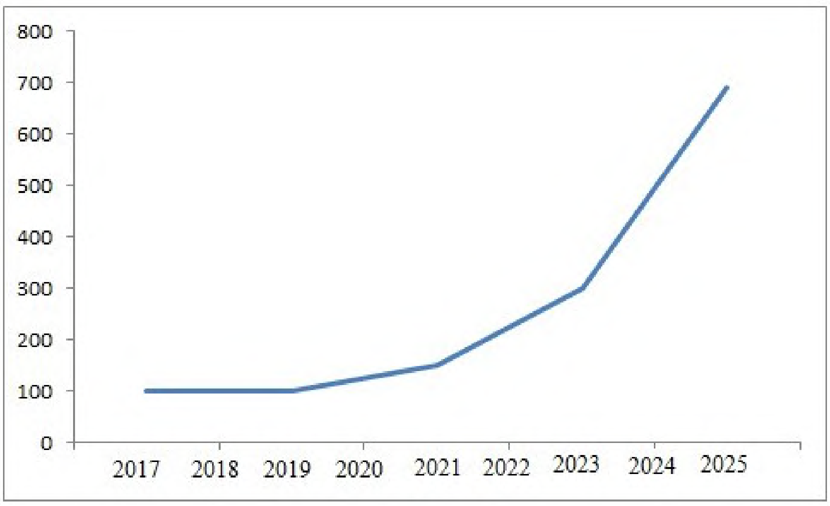

Figure 7. Graph of the growth of the population under study.

Any modeling process goes through several stages: observation of the object of modeling, accumulation of facts and phenomena, doing experiments; meaningful statement of the problem, schematization, formalization of facts, phenomena, certification, formulation of the technical task for model development; conceptual formulation of the modeling problem; mathematical formulation of the problem; checking the correctness of the model, consistency within the mathematical model, qualitative analysis of the model; selection and development of methods of solving, solution of the problem proper by analytical or numerical methods; checking the adequacy of the model to reality (model verification); practical use of the constructed model.

Mathematical modeling, in the case of a properly constructed model, helps to see what is difficult or impossible to verify in an experiment, allows you to reproduce such processes, the observation of which in nature would require a lot of effort and time. In mathematical models, you can 'consider' different options – to establish various connections, combine individual factors, simplify or complicate the structure of the system, change the sequence and strength of influence on it. All this makes it possible to better understand the mechanisms that operate in natural conditions.

The expediency of using the proposed method is justified by the following factors: students' comparative analysis of mathematical methods; making decisions on the feasibility and limitations of using a particular method; implementation of joint activities for modeling and development of software applications; mutual testing, debugging of created software products; analysis and results.

At realization of such technique collective forms of activity are used: pair work; group educational and cognitive activities; personal-role. Therefore, the following components of professional competence must be preformed in students: the ability to carry out information retrieval activities; skills of formalization and design of algorithms; proficiency in programming languages; skills of using digital technologies in solving practical problems; competency in mathematical apparatus and basic scientific concepts.

5. Conclusions and prospects for further research

Internal disciplinary integration can be implemented on the basis of the model nature mathematics computer science. The physical essence of this model of integration: natural processes are described in models by mathematical methods, followed by use in computer modeling.

The orientation of the educational process on the development-productive integrated approach has several positive aspects: the effectiveness of the formation of students' skills in modeling; the effectiveness of training in comparison with the subjects of professional orientation, which form the algorithmic competencies of students, through the possibility of intradisciplinary integration in the process of joint activities. Our research and our own experience suggest that the level of interest in performing such research among students is growing and contributes to the development of future professional competencies.

Intercomponent integration can take place between different disciplines of a certain cycle of both levels of higher education (for example, Zoology, Integrated Educational Practice Zoology, Phylogeny, Biogeography and Evolution of Life), and between disciplines of different cycles.

Verhulst's mathematical models were used to reproduce biological processes; Arima; Leslie and the exponential law of direct proportional dependence or proportional rate of reproduction on the number of individuals of a population. The implementation of the given mathematical models is possible using the programming environments Python, C♯, C++ and the mathematical package MathCad.

The application of interdisciplinary integration in teaching allowed to direct the content of training to get acquainted with the methods of modern systems research, to master the knowledge and skills of computer modeling for indepth study, quantitative and qualitative analysis of objects (phenomena, processes) in various fields.

At the present stage of integration in education it is necessary to restructure the activities of the teacher. Integration as a requirement to unite the components of learning objects into a single whole is a necessary didactic tool by which a holistic view of the object being studied is created, interdisciplinary competence is formed. With the help of multilateral relations, the foundation is laid for the formation of skills for a comprehensive vision of the problems of reality, diverse approaches to their solution.

Involvement of computer mathematics systems and the latest programming environments have contributed to the progress of the method of computer modeling of biological problems based on their mathematical models and popularization in everyday educational practice. The field of knowledge has been singled out, where basic research in mathematics and computer science is successfully combined with application in other sciences; mostly this process of creating a computer model is left behind. We see the prospect of further research in the study of the possibilities of software implementation of algorithms for describing the state of populations within a certain geographical area of Ukraine.

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The effect of the flipped classroom model on quality of the students‘ performance in biology education in high school

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The effect of the flipped classroom model on quality of the students‘ performance in biology education in high school

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Abstract. This study investigated the effectiveness of flipped classroom model (FC) and traditional classroom model (TC) in Biology on the quality of the high school students‘ performance. The research sample consisted of a total of 280 first grade high school students in Novi Sad, Serbia. The students in the experimental group learned Biology topic through the FC model, whereas the students in the control group were taught the same topic by the TC model. The instruments used in the research (the pretest and the posttest) contained the questions belonging to three different levels of cognitive learning according to the revised Bloom's Taxonomy. The results indicated that students that were instructed by the flipped classroom in Biology performed better on the posttest as a whole, and in solving the tasks of all three levels of knowledge (remembering, understanding, and applying) than those instructed by the traditional teaching method. On the basis of the obtained results, a grater implementation of FC model in high school biology teaching is recommended as a way of improving the quality of biology teaching in our and other countries over the world and the level of our students‘ digital competencies.

1. Introduction

The wide application of information and communication technologies in the field of education has led to the fact that special attention is paid to new teaching approaches in educational institutions. The growing popularity of computers and network technologies, high availability of technological devices to teachers and students at school and at home, high confidence of students in information technology, ease of acceptance of technological innovations by students, all this imposes the need to integrate digital technology into teaching and learning processes, at all levels of education [1–3]. Given this, recent research in the field of education emphasizes the need to apply innovative teaching approaches that are supported by digital technologies, and at the same time oriented towards active involvement of students in the teaching process [4]. One of the more popular modern approaches whose application in the teaching process is recommended by a large number of researchers is the Flipped Classroom model [5–8]. Flipped Classroom is a pedagogical model that obliges students to access various digital teaching content (videos, multimedia presentations, etc.) before class, which introduces them to the content that will be deepened in class, and that deepening of knowledge in class is done through practical activities students, solving specific problems, applying acquired knowledge in new and different situations, as well as productive and creative discussion [9–12]. This teaching approach puts the student in the center of attention. Thus, in a FC, the focus shifts from the teaching process to active student participation and learning, creating conditions for better interaction among students themselves, as well as between students and teachers, and developing students‘ functional digital competencies. This model is said to be flipped because what used to be done at school / college is now done at home and vice versa [9]. The number of research studies examining the impact of flipped classroom on student performance in Biology education has increased in recent years [13–19]. Although all the above researchers researched points out the FC as a good alternative to traditional classroom, there are also those studies that showed that traditional teaching was more efficient in terms of student performance (at the level of knowledge and application) compared to FC [20]. Considering that in the last few years in the Republic of Serbia, thanks to the enthusiasm of a number of biology teachers, educational material in the form of short Youtube videos for the application of FC has been prepared and made publicly available, one of the key preconditions for its application in biology teaching has been provided in both primary and secondary school. This created opportunities for greater implementation of this model of work in the teaching of biology, but also to test the effectiveness of this model in the implementation of biology programs in teaching practice. Therefore, the aim of this paper was to examine the effects of FC model on the quality of students‘ knowledge at three different cognitive levels (remembering, understanding and applying) according to the revised Bloom‘s Taxonomy [21] in biology teaching in high school, compared to traditional teaching.

2. Concept of flipped classroom model

The Flipped Classroom approach, which is an increasingly popular and present model of learning in classrooms around the world, began to be applied by two chemistry teachers, Jonathan Bergmann and Aaron Sams, in their chemistry classes in 2012. This teaching approach has developed gradually, over time, out of the need to improve the quality of teaching through the application of technology [6]. The Flipped Classroom is a model of work in which the roles of teachers and students change, compared to the traditional model of work. In FC students gain the basics of teaching content by watching and listening to online video material and solving certain tasks, which provide them with preparation for active participation in the teaching process in class. The role of the teacher in the TC is the provider of information, while the role of the student is the recipient of information. Unlike the TC model, in the FC model the teacher has the role of a person who provides assistance and directs the student to an active role in the teaching process [22].

Observed through teaching practice, the FC model includes two groups of activities: pre-class and in-class learning activities. Within the pre-class activities, the teacher first selects teaching units suitable for processing using the FC model. He/she then prepares the necessary teaching material in the form of educational video lessons (lectures that he records himself) or finds appropriate online multimedia educational material in which the material is presented in a concise form and distributes it to students. On this occasion, educational material designed for reading, listening and watching can be integrated with online communication in order to increase the interactivity of learning. After that, students have homework to solve, and it is related to the reviewed educational material, in order to gain an understanding of the basic biological concepts that will be covered in more detail in class. As part of preparing students for the class, students can make a brief concept of the reviewed material, extract key information, write down ambiguities and difficulties encountered during reviewing the material, write down a few questions that were not answered in the material and want to know the answers. In this phase of preparation for the class, students should be given freedom of expression, in accordance with their abilities and interests, which to some extent achieves individualization in teaching and learning. The video also allows for individualization. Namely, each student can stop or rewind a certain part of the recording faster, to study the material at home, outside the classroom and the time frame of the class, at a time that suits him best [6,23,24]. With this preparation of students for the class, much more time remains in the classroom for conducting in-class activities [25]. In-class activities include more meaningful and creative student activities related to problem solving and practical application of knowledge, in a group form of work that contributes to deepening knowledge and understanding the essence of the studied material [26–28]. The role of the teacher in the class is to help the students, not to give information in a ready-made form. This organization of class activities allows the teacher to devote more time and attention to students who learn more slowly [6]. In this way, the role of the teacher has changed: he becomes someone who has time to deal with each student separately and can be a leader, organizer and mentor. The teacher guides the students in conversation, gives feedback and advice [29]. Such procedures in class complement the individualization of teaching and learning, which is one of the most important advantages of this model of teaching compared to traditional teaching.

Many authors emphasize the great pedagogical value of a Flipped Classroom, because after their research they came to the conclusion that this teaching model helps the teacher in training students for critical thinking [30], causes students to become more open to collaboration with peers [26], and positively affects student achievement [14, 24].

Although the value of the Flipped Classroom is emphasized in a large number of literature sources, there is still an insufficient number of published empirical research papers examining the impact of FC on improving teaching, learning and student achievement, especially on the quality of students‘ knowledge [31]. The results of this study will provide evidence of prevailing situation, and provide biology teachers with useful suggestions for the appropriate application of FC in teaching practice.

3. Methodology of research

Experimental research was used in this study as the research methodology. According to the aim of the study, the pedagogical experiment was conducted with parallel groups. Students from the experimental group (E) studied the contents of the “Cell Structure and Function” within the Biology classes for the first grade of high school by using the FC model, while at the same time, the students of the control group (C) learned the same contents by using the TC model. The two groups were then evaluated to identify differences in students‘ cognitive performance, by levels of knowledge: remembering, understanding and applying according to Bloom‘s revised Taxonomy.

3.1. Sample of research

A sample of convenience consisted of 280 students from one high school in Novi Sad, Serbia, who participated in the research. In total, every group (E and C) consisted of 140 students. The respondents were the first grade student of high school, aged from 14 to 15. Prior to the start of the research, it was established that there was no students in the E group who did not have both a computer and Internet connection at home, which enabled them to participate in the research.

3.2. Instruments and procedures

The experiment was carried out in the school year 2018/19, during regular Biology classes, on the contents of the teaching topic “The Cell Structure and Function” which is provided by the Biology curriculum for the first grade of high school [32]. Teaching units/contents taught to the students in both groups during the experimental research are: 1. Cell - meaning, chemical composition; 2. Cell membrane - structure and function; 3. Transport of substances across the cell membrane (passive and active transport; exocytosis and endocytosis); 4. Transport of water and minerals through the plant cell membrane, plasmolysis and deplasmolysis; 5. Exercise: Investigation of the effects of turgor pressure in a plant cell; 6. Cellular organelles in plant and animal cells; 7. Cell metabolism; 8. Basics of protein synthesis; 8. Sheet - material, functions; 9. Photosynthesis, chemosynthesis, nitrification; 10. Cellular respiration and fermentation. The work with students from both groups encompassed a total of 12 regular class periods, each lasting 45 minutes. At the beginning of the research, prior to teaching the topic "Cell Structure and Function", both the experimental group and the control group of pupils were tested with the pretest in order to synchronize the previous knowledge of students in both groups. The pretest contained 18 questions arranged by complexity levels, according to the revised Bloom‘s Taxonomy (6 questions for cognitive level remembering; 6 questions for level understanding and 6 questions for level application), to examine the quality of cytology knowledge acquired during the previous or primary education. After pretesting, teaching of the topic "Cell Structure and Function" was implemented with different teaching approaches: the FC approach in the E group and the TC approach in the C group. Flipped classroom approach included pre-class and in-class activities for each biology class, during the complete duration of the experimental research. Before each biology class, students were required to review a short video summarizing the lesson material that will be deepened in 10-15 minutes. In addition to this activity, the students had the task to solve the appropriate questions on the instruction sheet that referred to the reviewed material. The video, which was planned as part of the pre-class activities, students were able to watch and listen to an unlimited number of times, at a time and place that suits them. Except for the lessons of material processing, and for the lesson where the realization of the exercise was planned, the students had the obligation to prepare by watching a video in which the teacher demonstrates the exercise and solves questions given on the instruction sheet, which related to the reviewed exercise. In-class activities in biology classes, which were planned for the processing of materials (on lecture days) and the realization of the exercise, included various interactive activities in which the teacher sought to contribute to a deeper understanding of the material and the essence of the material. The overview of the activities in the class and their duration was as follows: for the first 10 minutes, the teacher checked the understanding of the content presented in the video by giving the students answers to the questions asked on the instruction sheet. In this part of the class, students had the opportunity to ask additional questions in order to clarify possible ambiguities or discuss a certain part of the recorded material. After the introductory part of the class, in the basic part of the class which lasted 25 minutes, the students actively approached solving problem tasks in groups, in order to mentally activate students and deepen the content being processed. In the final part of the class, which lasted 10 minutes, the teacher used a dialogue method at the level of the whole class to check the understanding of the essence of the material, encourage the application of knowledge in analogous situations and correct omissions. The overview of activities in biology classes in C group that were realized by TC model is as follows: the first 10 minutes the teacher explains the difficulties and problems that students had with previous material, then in the main part of the lesson lasting 25 minutes new material was processed and the remaining 10 minutes of the final part of the class, students solve problem tasks. Thus, the traditional approach significantly less time in class is dedicated to understanding knowledge and deepening the content, compared to the flipped classroom approach. Upon completion of the analysis of the teaching topic "Cell Structure and Function", students from both groups took the posttest the same day. The posttest contained 18 questions arranged according to levels of complexity according to the revised Bloom‘s Taxonomy, in order to examine the quality of students‘ knowledge of biology program content, which was processed in the experimental part of the research using FC models and TC models.

3.3. Ethical consideration
The consent of the principal, biology teacher and school board was obtained for the implementation and realization of the experimental research.

3.4. Data analysis
PSPP (GNU Project) and Microsoft Excel 2016 (Microsoft) software packages were used for statistical processing of data obtained during the research. Mann-Whitney U test and Wilcoxon signed-rank test were used to analyze the correlation of the two variables.

4. Research results and discussion
In order to unify the students of E and C groups, at the beginning of the research, students were tested, and then their previous knowledge about the Cell acquired during primary education was compared. The calculated weight index of the pretest was 73.15%, which corresponds to the tests of moderate weight [33]. The index of discriminativeness of the test is 0.35, so the pretest can be classified as a test of good discriminantness [34]. The analyzed results obtained on the test showed that the students of group E on the pretest as a whole achieved an average of 13.06 points (72.55%), while the average success of students of group C was 13.05 points (72.5%). Considering the success of students of E and C groups at individual cognitive levels, it was concluded that students of both groups achieved the greatest success at I level of knowledge (E group: average 5.33 points - 88.83%, C group: average 5.30 points - 88.33%). Weaker success of both groups was achieved at the II level of knowledge (Group E: average 4.01 points - 66.83%, Group C: average 4.05% - 67.5%). The students of both groups achieved the weakest success at the III level of knowledge (E group: average 3.72 points – 62%, C group: average 3.7 points - 61.67%). The Mann-Whitney U test for two independent samples tested the significance of the differences in the performance of students in groups E and C, at individual cognitive levels and at the test as a whole. The results of this test are shown in table 1.

Based on the results of statistical analysis and obtained p values ($p > .01$), it was concluded that there is no significant difference in the number of points achieved between students in groups E and C, at individual levels of knowledge according to revised Bloom‘s Taxonomy and the test as a whole. This proved that the E and C groups before the introduction of the experimental factor were homogeneous according to the quality of knowledge achieved in the pretest. At the end of the experimental part of the research, both groups of students solved the posttest. Based on the calculated weight index, which is 76.28%, the posttest can be considered a moderate weight test. The discrimination index of the posttest is 0.39, which corresponds to the tests of good discrimination. The analyzed results obtained on the posttest showed that the students of group E on the posttest as a whole achieved an average of 14.95 points (83.05%), while the average success of students of group C was 13.01 points (72.28%). Considering the success of students of E and C groups at individual cognitive levels, it was concluded that students of both groups achieved the greatest success at I level of knowledge (E group: average 5.56 points - 92.67%, C group: average 5.11 points - 85.17%). Weaker success of both groups was achieved at the II level of knowledge (Group E: average 5.02 points - 83.67%, Group C: average 4.11% - 68.5%). The students of both groups achieved the weakest success at the III level of knowledge (Group E: average 4.37 points - 72.83%, Group C: average 3.79 points - 63.17%). The results achieved on the posttest as a whole and by cognitive levels show differences in favor of the E group of students. The significance of the obtained differences in student achievement between students of groups E and C was checked by the Mann-Whitney U test for two independent samples. The results of this test are given in table 1.

Based on the results of statistical analysis and the obtained p values ($p < .01$), it can be concluded that there is a statistically significant difference in the number of points achieved between students of E and C groups, at individual cognitive levels and at the posttest as a whole.

Table 1. Results of the Mann-Whitney U test for differences in performance on the pretest and the posttest between groups E and C.

		I level	II level	III level	Total achievement
The pretest	Mann-Whitney U	8057.00	8111.50	8325.00	8402.50
	p	.513	.576	.879	.937
The posttest	Mann-Whitney U	6630.00	6370.50	5850.00	6002.50
	p	.001*	.000*	.000*	.000*
*Sig. $p < .01$					

Table 2. Results of comparison of performance achieved on knowledge tests for each group individually.

		Differences in achievement between tests	p
E group	The pretest - The posttest	-1.89	.000*
C group	The pretest - The posttest	0.04	.823
*Sig. $p < .01$			

Also, the obtained results indicate that the biggest difference in the performance of students of E and C groups was achieved at the II level of knowledge, and then at the III level of knowledge in favor of the E group of students. This indicates the positive impact of flipped classroom on the quality of students‘ knowledge, especially in solving tasks that require understanding and application of knowledge in biology, in relation to the impact of traditional teaching. In order to examine the progress of students in groups E and C during the experimental research, a comparative analysis has been used for the results achieved on knowledge tests (pretest and posttest) for each group of students individually. In order to determine between which tests (knowledge tests) within each group of students there are significant differences in achievement, the Wilcoxon signed-rank test was performed. The results of this test are shown in table 2.

The results of the statistical analysis indicate that the students of group E on the posttest significantly improved, compared to the pretest ($p < .01$). Progress of group E can be attributed to their learning, which was individualized and independent. They invested additional effort in independent preparation for the class by reviewing the appropriate video created for the processing of certain teaching content, so that the time in class was not used for frontal lectures by teachers, but for deeper analysis of content, essential understanding of the subject matter through interactive activities with other students and the teacher. So, before entering the classroom, the students were already familiar with the cognitive aspect of the class, and they viewed the process of learning and acquiring biological knowledge as an individual thing that does not depend only on the teacher. The teacher discreetly led the lesson from the background, leaving the students to be maximally active. Such actions of teachers, creative behavior of students during the processing of the teaching topic “The Cell Structure and Function”, participation and initiative of students in given school activities, interpersonal relationships in classes interested students in Group E for work and personal progress. Integration of all mentioned elements of the flipped classroom improved the teaching of biology and provided students with functional knowledge. Unlike the students of group E, the achievements of the students of C group on the pretest and the posttest were very similar ($p > .01$). Such results are most likely a consequence of the unchanged traditional way of working. During the processing of the topic “Cell Structure and Function”, the students of group C listened frontal lectures of the teachers, participated to some extent in the discussion about the studied contents, but not enough to achieve a better learning outcome. Their insufficient involvement in the teaching process and the lack of initiative to initiate a discussion regarding the studied content led to the realization of significantly lower achievements on the post-test compared to the students of Group E. The findings obtained in this study are consistent with the results of other researchers who have applied the FC model in teaching biology [14,17,19], as well as other subject areas: teaching chemistry [24], in math, science and social studies [35], in computer interaction course [36]. Flipped Classroom improves the quality of students' knowledge by using techniques of active involvement of students in the teaching process and thanks to the mutual interactions of students, as well as students and teachers [37]. Active engagement of students in solving problem tasks, as well as tasks that require the application of knowledge in new and different situations, affects the expansion and deepening of knowledge. Thus, the application of the FC model requires teachers to provide an interactive learning environment, and puts themselves in the role of moderators who will lead students in a meaningful and creative way to acquire new and functional knowledge. Also, the teacher should carefully choose publicly available educational material or create their own educational content for students within the pre-class activities, in which the material will be presented concisely, interestingly and to keep students' attention. A Flipped Classroom is a teaching approach that respects differences among students and enables individualization of the learning process, because students choose the type of teaching material, time, place of learning, as well as the pace of learning [38]. Considering research whose results have shown that FC has no significant impact on improving learning compared to the traditional approach in biology and related biological disciplines [39–41], and that traditional teaching can contribute to better student performance in the veterinary medicine course compared to the traditional approach [20], it is necessary to conduct more similar research on the effects of FC on various aspects of teaching and learning in order to draw more valid and reliable conclusions, recommendations and strategies for application of this models in the teaching process.

5. Conclusion

The results obtained in this experimental study showed that there is a statistically significant difference in the achievements of students in groups E and C, in favor of the application of flipped classroom model in teaching biology in high school, compared to traditional classroom. The application of the FC model in biology teaching has a positive effect on the quality of students' knowledge and their practical applicability, because this study showed that this innovative teaching approach has a significant impact on the development of competencies especially for problem solving and critical thinking, as well as the acquisition of functional knowledge, as evidenced by the fact that there is a statistically significant difference in the achievements of students E and C groups achieved on issues of second and third cognitive levels, which require remembering and applying acquired knowledge. Based on the results of this study, the flipped classroom should take an appropriate place in the teaching of biology in high school. The results of this research can be an incentive to conduct future similar research, but on a larger sample, in order to obtain more reliable results in the study of this innovative model of work. Another limitation of this study that should be removed in future research is the length of the experimental research. A six-week intervention is a relatively short period to test the effectiveness of some teaching approaches, so the experiment should take longer. Also, this paper lacks the effects of FC on knowledge retention, so this effect should be investigated in future research. Considering the positive influences of FC on the quality of biology teaching in high school in spite of some limitations, this study suggests several implications for educators. In order for the flipped classroom to be properly implemented in the teaching process, it is necessary for the teacher to follow modern trends in methodological research, to improve his professional and didactic-methodological knowledge, as well as to develop information technology skills to apply them in his teaching practice.

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ICT-based assessment of cognitive load in chemistry learning

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ICT-based assessment of cognitive load in chemistry learning

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Abstract. The article is devoted to studying and preventing an excessive increase in the cognitive load of university students studying chemistry using various electronic resources. The experiment involved 49 third-year students of the Faculty of Chemistry who studied organic chemistry. A homemade software was developed to measure the level of cognitive load using the secondary problem method. Cognitive load levels were studied depending on the types of used electronic resources. The studied resource types are texts of different levels of complexity, audio and visual materials in different combinations. The load values were measured for each respondent, expressed in relative quantitative units and averaged over the whole student group. In parallel, the preferred learning styles among the respondents were identified according to the Index of Learning Style of Felder-Soloman. A correlation was established between the preferred learning styles of students and the cognitive load they feel when working with electronic resources. The factors that affect an optimal set of educational resources were identified for student groups with various learning profiles. The results of factor analysis allowed the authors to assess the contribution of different learning styles in the formation of cognitive load in the use of different electronic resources. The techniques described in this article allow one to control cognitive load, predict and prevent its excessive increase.

1. Introduction

Electronic resources are widely used in training future chemical specialists [1, 2, 3, 4]. These are resources controlled by a computer and often require a peripheral device. Various aspects of the term “electronic resources” refer to the digital form of data representation, computer tools and software for their reproduction and management, electronic environment for the distribution or exchange of data, etc. Visualisations are most often used to represent chemical information in images. In the e-resources, they can be static and dynamic, display objects and phenomena close to their natural or abstract form, and provide opportunities for simulation and modelling.

Despite the tremendous educational potential of e-resources, their application does not always increase productivity and improve the quality of education [5, 6, 7]. Often, this is due to a significant increase in students’ cognitive load with a non-optimal combination of educational material presented in different formats [8, 9, 10]. Predicting the direction of load changes and developing methods to prevent excessive increases during e-resource training is an essential and urgent pedagogical problem.

One can distinct indirect or direct methods measure cognitive load [2, 4, 11, 12]. Indirect methods of determining cognitive load are based on assessment scales and questionnaires and have many disadvantages. Direct methods allow to control the change of speed of reaction of respondents or compare values of their physiological characteristics before and during educational work. Usually, such methods are more accurate. However, measuring parameters that change according to the mental effort in the cognitive process (variability of heart rate, respiration, visual scanning, etc.) is not always easy to incorporate into the educational process.

Today there are no universal, automated and generally accepted methods for assessing cognitive load, which would be perceived as standard [13, 14, 15]. A secondary task method can be considered the most optimal strategy in education. Combined with the control of the success and quality of the acquired knowledge, it allows assessing objectively and quantitatively the resulting load and studying its dynamics with sufficient accuracy. Researching with its help requires automation of measurements and result processing.

The relationship between cognitive load and student achievement is widely discussed [16, 17, 18]. This connection is primarily related to the psychophysiological characteristics of students, and this factor sometimes limits the increase in learning efficiency [19, 20, 21, 22].

As already mentioned, with the active use of electronic resources, it becomes necessary to control changes in students' cognitive load and take measures to prevent its excessive increase. In studying fundamental chemical disciplines, this primarily applies to students' work with visualisations of the material [23, 24, 25]. At the same time, as shown in many studies, the perception of different visualisations depends on students' prevailing learning styles [26, 27, 28]. Therefore, it is logical to assume specific correlations between the level of cognitive load, the type of electronic resource, and students' learning preferences.

Modern education is student-oriented and requires consideration of students' preferences for teaching methods [4, 29, 30, 31]. This approach will allow learners to use and improve existing cognitive functions for rapid development. Students differ significantly in the speed and method of assimilation of new information, confidence in its processing and use. The development of information and communication technologies (ICT) significantly expands the range of electronic resources and tools used in the educational process, especially in teaching natural sciences [32, 33]. Accordingly, the individual perception of different resources is becoming increasingly important.

One needs to note existing criticism of the very concept of learning styles [34, 35]. However, the very idea of various approaches to learning among students is usually not disputed. On the contrary, the concept of correlation between learning styles, teaching methods and academic performance is still under much discussion.

This work aimed to evaluate the value of cognitive load experienced by students learning organic chemistry topics using a textbook with different electronic resources. Homemade software based on a secondary task method was developed for measuring cognitive load as a function of e-resource type and available students' learning preferences.

2. Experimental

2.1. Measurement of cognitive load

Studies of factors that affect students' cognitive load during e-resources-based training were conducted by the method of the secondary task. The essence of the method is to perform two tasks simultaneously. One of which (primary) is educational, and the second task (secondary) allows one to determine changes, such as the speed of the individual's response to the signal (visual, audio). The longer the response time, the higher cognitive load is experienced by a respondent.

The study's hypothesis was the assumption that the non-optimal combination of multimedia materials increases students' cognitive load when performing the main task. It increases the time required to complete the secondary task. Fixing the time difference allows one to quantify the degree of cognitive load and its change depending on the type of educational task, psychological characteristics of students, or other factors.

Forty-nine 3rd-year students of the Faculty of Chemistry of Olesj Honchar Dnipro National University participated in the experiment when studying organic chemistry. Students were offered to work with an interactive electronic textbook "Organic Chemistry" [36] to perform the main task. This textbook was chosen for experiments because it contains many multimedia materials (images in various formats, audio commentary, video, animations, interactive games, etc.) of different types. It allowed arranging a series of experiments when each student performed a few tasks of similar complexity but illustrated with electronic resources in different formats.

A homemade program was used to measure the total cognitive load of students. The program has a simple, straightforward interface. The central part of the working window of the program is the frame/window where the training material is placed. For example, video with audio illustrates laboratory work, as shown in figure 1.

The measuring button was located at the vertical service panel in the upper right corner of the screen (figure 1). The square button periodically changes colour from green to red every 5 or 10 seconds. The secondary task was to press the square button as quickly as possible when the button changed its colour [37]. The time between changing the button colour and pressing the button is recorded. A measured delay in pressing the button is considered a measure of the cognitive load.

Control elements are located below the measuring button. A slider allows one to change the time allotted for displaying one colour's button until its following change. The "Get Started" button is used to start, stop and restart the program if necessary. The "View Results" button opens an Excel file with recorded measured intervals, as shown in figure 1. The program provides the possibility of statistical processing, storage and systematisation of all measurements. The button "Exit" is located in the lower right corner of the service panel.

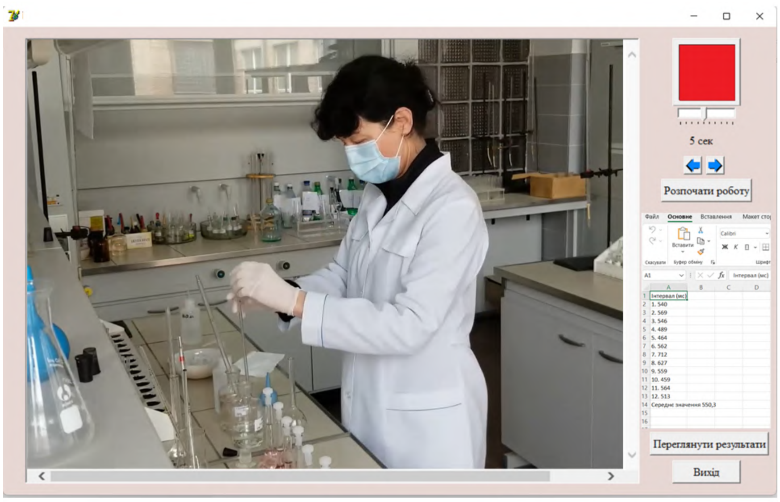

Figure 1. Screenshot of the homemade software to measure cognitive load by a secondary task method.

The textbook contains a large amount of multimedia material (images in various formats, audio commentary, video, animations, interactive games, etc.). It allowed arranging a series of experiments when students worked with electronic chemical materials in various formats.

A homemade program was used to measure the total cognitive load of students. The program has a simple, straightforward interface. The central part of the working window of the program is the frame/window where the training material is placed. The measuring and control buttons were located at the vertical service panel on the right side of the screen. The secondary task was to press the square measuring button in the upper right corner as quickly as possible when the button changed its colour from green to red [37]. The time between changing the colour of the measuring button and pressing it was recorded. The data measured was displayed on a personal computer.

Control elements are located below the measuring button. A slider allows one to change the time allotted for displaying one colour's button until its following change. The "Get Started" button is used to start, stop and restart the program if necessary. The “View Results” button opens an excel file with recorded measured intervals. The program provides the possibility of statistical processing, storage and systematisation of all measurements. The button “Exit” is located in the lower right corner of the service panel.

In the course of the experiment, the change of students’ cognitive load was studied under the influence of:

1. Changes in the form of presentation of the material. Respondents were asked to study chemical material of approximately the same level of complexity according to three alternative schemes of data presentation. They read text from the screen, read text from the screen while watching animation, and watch video demonstrations accompanied by audio.

2. Changes in the level of complexity of the task. Respondents worked with texts of varying complexity in reading experiments to do this.

3. Effects that distract from the task. Respondents watched videos that either contained or did not bright fragments, like explosion or fire, diverted from the main learning task.

Each student performed five experiments 1-5 and repeated 5-6 times each. The description of these experiments is shown in table 1. The average results for each respondent, delivered in a particular experiment, were calculated for further analysis. In addition to the above five experiments, the preliminary test was performed without a learning task (experiment 0 - blank test). It was used to normalise the experimental data on the individual reaction rate of each respondent.

Table 1. Description of the experiments.

No	Short name	Conditions under which the individual reaction rate of the respondents was measured
0	Blank	In the absence of an educational task
1	Simple text	While reading simple texts
2	Complex text	While reading complex texts
3	Text+animation	When working with text and viewing animations
4	Video+audio	When watching a video with audio
5	Video+audio with explosion	When watching a video with audio, accompanied by explosions or fire flashes

The average reaction time (the delay in responding to the button colour change averaged over 5-6 attempts) obtained during the preliminary test is denoted by t_0. The individual respondent results of the blank test varied quite widely. The main reason for this is individuals’ psychological or physical (for example, related to visual impairments) characteristics.

The relative response rates R_n=t_n/t_0 normalised to t_0 were used in the following analysis instead of the absolute values t_n in seconds to minimise the influence of individual characteristics. So, the ratio R_n shows how many times the reaction rate of each student has changed when performing the primary task in experiment n compared to the reaction rate in the blank experiment.

The study of the influence of cognitive load was started in experiments with texts of different levels of complexity (at first easier and then more difficult). These experiments are named the first and second experiments (table 1). The measured response times are denoted t_1 and t_2, respectively.

The third experiment (t_3) aims to study the load of text and parallel animation.

The fourth (t_4) and fifth (t_5) experiments focused on the effects of simultaneous video and audio use. In the latter case, the video demonstration contained blazing effects (explosion or flash of fire).

2.2. Identification of learning preferences
Preferred learning profiles were identified by R. Felder-B. Soloman method for each of 49 students who took part in the experiment. Based on the individuals' data, the preferences of the student group were also identified. The instrument, known as the Index of Learning Style (ILS) [38, 39], was used. More detail of the instrumentation is given elsewhere [40, 41].

The ILS allows one to estimate learning preferences in four complementary dimensions. Each of the four dimensions consists of a pair of a style and antistyle or two contrasting styles. The information input occurred via visual (vis) or verbal (vrb) channels. Perception of information proceeds through either sensing (sen) or intuition (int). Understanding information took place by using a sequential (seq) or global (glo) approach. Datastream is processed in either an active (act) or reflective (ref) way.

A 12-point scale (0 to 11 points) was used to quantify students' preferences for each of four dimensions. A particular individual style or corresponding antistyle dominate if the calculated score of an individual or average score of a student group ranges from 6 to 11 points or 0 to 5 points, respectively.

2.3. Statistical treatment
The SPSS package was used to process the obtained results statistically [42]. The main characteristics of descriptive statistics were calculated. The results were expressed as the mean values with standard errors of the mean. All data were tested for normal distribution with the Kolmogorov-Smirnov test.

The t-test for paired samples was applied to take into account the impact of individual characteristics of respondents, such as, for example, the individual reaction rate. This criterion is used for dependent samples. As opposed to the t-test for independent samples, the differences between the values of two variables (between the results of two compared experiments) are calculated for each respondent. And then, it is checked whether the average of these differences differs from zero.

The principal component analysis method, the simplest type of factor analysis, was used with an orthogonal Varimax rotation and Kaiser normalisation [43]. It allows one to simplify structures and illustrate large data sets by calculating a smaller number of meaningful linear combinations (newly defined principal components or factors) from a large number of variables (learning styles). In essence, this method consists of selecting a new orthogonal coordinate system in observation space. As the first factor, a direction along which an array of observations has the most considerable variance is selected. In other words, the first task of factor analysis is to select interacting variables whose cross-correlation determines the largest share of the total variance. These variables constitute the first factor. Then the first factor is excluded from further consideration. The following factors are also selected to maximise the remaining part of the total variant. Orthogonality between all factors is an additional condition for principal component mapping. A part of the total variance linked to a given factor decreases with its number

3. Results
3.1. Determination of the level of cognitive load
Histograms illustrating the distribution of the number of students by the R_i value are shown for experiments 1, 3 and 4 in figure 2. At first glance, the distributions obey the normal law. At the same time, these data illustrate the existence of significant scatters between the results of individual students. Thus, the results obtained require additional analysis to determine the statistics to be used.

Descriptive statistics for the R_n values in experiments 1-5 are given in table 2. The results are checked for the distribution normality by the Kolmogorov-Smirnov test. It is shown that the obtained data meet the criterion of normal distribution. So, it is advisable to compare mean values and use standard t-criteria for data analysis.

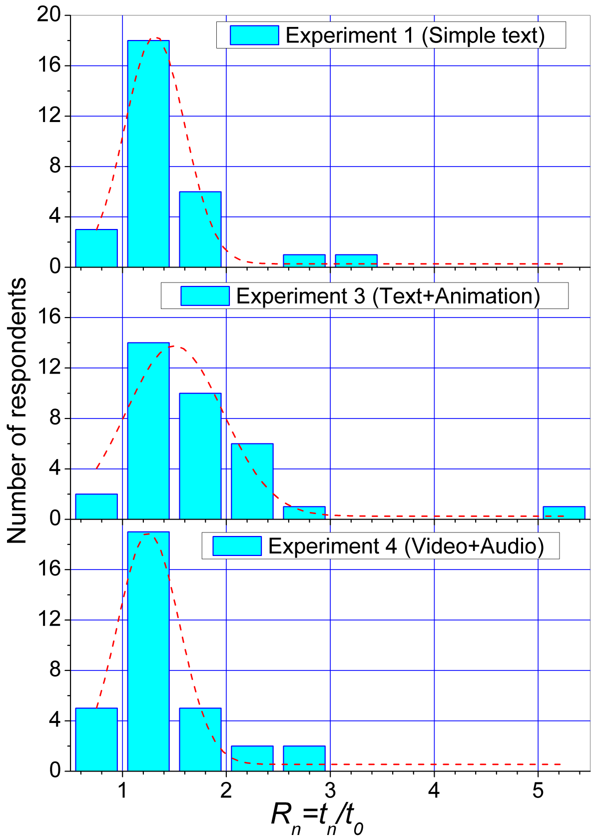

Figure 2. Histograms illustrating the respondent number as a function of R_n for experiments 1, 3 & 4.

The mean values of the relative reaction rate differ markedly (table 2). The t-test for paired samples was used to assess the statistical significance of the difference between them. Comparing the reaction rate values using the t-test for experiments 1, 3 and 4 are contained in rows 2, 3, 8 of table 3. In two of the three cases being compared, the difference between the mean R_n values meets the criterion $p < 0.05$.

When using text with animation, the load is higher than reading text or watching videos with audio. The invented differences are statistically significant. At the same time, the slight difference between R_1 and R_4 does not exceed the statistical error. In other words, there is no significant difference between the level of load when using text compared to watching videos with audio.

Another task solved during the experiments was to compare the load that occurs when using the text of different complexity (experiments 1 and 2). The comparison results (row 1 in table 3) indicate an indisputable positive correlation between the level of test complexity and the level of cognitive load.

Table 2. Descriptive statistics and results of data verification by the Kolmogorov-Smirnov test, indicating the presence of a normal distribution of the results of experiments 0 - 5.

Experiment No	0	1	2	3	4	5
Number of respondents	34	28	30	34	33	24
The mean value of t_n, ms	530.4	777.2	904.1	835.8	658.9	1511.3
Kolmogorov-Smirnov Z	2.078	1.768	1.020	1.432	1.170	1.643
Asymptotic significance, p	0.000	0.004	0.025	0.033	0.019	0.009
$R_n=t_n/t_0$		1.410	1.810	1.700	1.380	3.120
Standard deviation, σ_R		0.083	0.166	0.138	0.089	0.830

Note: The distribution obeys the normal law if $p < 0{,}05$

The last task was to investigate the influence of bright fragments that distract when watching videos. The comparison of experiments 4 and 5 (row 10 in table 3) indicates a significant load increase with the appearance of such fragments. In general, the reaction time in experiment 5 was the highest compared to all investigations. However, a significant difference between R_5 and other R_n was not observed for all pairs of the experimental observations. Teachers should consider this and provide step-by-step interactive work to reduce cognitive load when working with different visualisation types.

Table 3. The results of comparing the averages using the t-test of paired samples.

No	Comparison of experiments	Average difference	Standard deviation	Standard error	t	df	Significance (2-tailed), p
1	R_1-R_2	-0.452	0.803	0.164	-2.753	23	0.011
2	R_1-R_3	-0.297	0.893	0.169	-1.765	27	0.049
3	R_1-R_4	0.005	0.522	0.101	0.047	26	0.963
4	R_1-R_5	-0.858	2.583	0.609	-1.410	17	0.177
5	R_2-R_3	0.0810	0.869	0.159	0.511	29	0.613
6	R_2-R_4	0.316	0.783	0.145	2.174	28	0.038
7	R_2-R_5	-1.350	4.372	0.932	-1.449	21	0.162
8	R_3-R_4	0.323	0.680	0.118	2.731	32	0.010
9	R_3-R_5	-1.375	3.935	0.803	-1.712	23	0.100
10	R_4-R_5	-1.836	3.740	0.780	-2.354	22	0.028

Note: The difference between R_n is significant if $p < 0{,}05$

3.2. *Effect of learning style*

Figure 3 illustrates the average learning profile of respondents (the student group profile) who participated in the experiments, compared with the average profile of natural sciences students [44, 45].

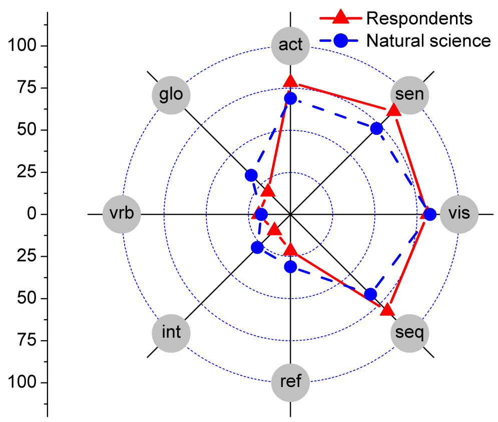

Figure 3. Generalised profile of learning styles of students majoring in natural sciences in comparison with the profile of participants of the experiment.

Both profiles are very similar. Among the four available dimensions, they demonstrate the predominance of active (act), sensing (sen), visual (vis) and sequential (seq) learning styles. The proximity of the profile of the studied group to the average of the whole direction of training can be an additional argument for the feasibility of analysing the impact of student learning styles by the Felder-Soloman method.

Testing was performed according to the t-test for paired samples. The average differences in R-scores between experiments R_n and R_m together with corresponding significance values were compared for the whole student group and subgroups formed by students with all eight preferences in learning styles. However, table 4 shows only the most fundamental results for solving the main task.

In most cases, the results for individual subgroups qualitatively correlate with the results of the whole student group. In some cases, the analysis of the behaviour of individual subgroups gives qualitatively new results. Thus, for respondents of the entire group and respondents with a preferred visual learning style, the load level in experiments 1 (text) and 4 (video+audio) is virtually the same. For respondents with a preferred verbal style, the transition to the use of video+audio format (involvement of the auditory canal in addition to the visual) leads to a statistically significant reduction in cognitive load compared to text-only (visual) data format.

Table 4. Average differences R_m–R_n in experiments 1 - 5 and the significance of the results p (*) for the whole group and subgroups with different learning preferences.

Indicator	Group	R_1-R_2	R_1-R_3	R_1–R_4	R_3–R_4	R_4–R_5
R_m–R_n	In whole	-0.452	-0.297	0.005	0.323	-1.836
p	In whole	0.011	0.049	0.963	0.01	0.028
R_m–R_n	Vrb	-0.558	-0.111	0.285	0.21	-1.779
p	Vrb	0.246	0.424	0.018	0.281	0.293
R_m–R_n	Vis	-0.377	-0.347	-0.065	0.418	-1.629
p	Vis	0.085	0.209	0.654	0.021	0.04
R_m–R_n	Ref	-0.853	-0.478	-0.234	0.494	-1.253
p	Ref	0.025	0.27	0.263	0.096	0.165
R_m–R_n	Act	-0.043	-0.11	0.256	0.254	-1.925
p	Act	0.74	0.197	0.005	0.05	0.126
R_m–R_n	Int	-0.721	-0.366	0.295	0.598	-0.011
p	Int	0.582	0.527	0.103	0.07	0.865
R_m–R_n	Sen	-0.398	-0.263	0.03	0.302	-2.098
p	Sen	0.05	0.2	0.792	0.039	0.05
R_m–R_n	Glo	-0.484	-0.484	0.027	0.437	-1.628
p	Glo	0.149	0.053	0.899	0.039	0.025
R_m–R_n	Seq	-0.368	-0.075	0.077	0.233	-1.797
p	Seq	0.098	0.675	0.144	0.146	0.344

(*) the difference between R_m and R_n is significant if p <0.05

In the act-ref dimension, respondents with an active learning style do not experience an increase in the load when changing the complexity of the text. In contrast, the complexity of the text has a significant negative impact on reflective students.

If we compare the results for text and video+audio, experiment 4 gives much better results (shows less load) than experiment 1 for a subgroup of active students. In turn, an increase in the load is observed for reflective respondents when watching video+audio compared to the study of texts. However, the calculated difference R_1–R_4 for ref students is not statistically significant. Reflective students can choose an acceptable learning rate, reducing the internal load. Working with text data may give them more room for reflection than other formats.

The division into these subgroups does not usually change the load level for intuitive and sensing respondents. The only exception is the difference in R_4–R_5. For the whole group and a subgroup of sensing respondents, explosions or fire flashes in the video significantly retard the reaction rate. The difference between R_4 and R_5 is about two units, and in both cases, this difference is statistically significant.

Regarding the subgroup of intuitive respondents, they do not actually show differences in experiments 4 and 5. This difference is minimised by significantly reducing not only R_5 but also R_4. Thus, intuitive respondents easily perceive educational data as video+audio. The presence of bright distracting fragments has a much smaller impact than for respondents with other learning styles.

The only feature of the respondents, divided into subgroups in the glo-seq dimension, is a slightly better perception of the format text+animation (reduced value of the parameter R_3) by students with a prevailed sequential style. As a result, the difference between R_1 and R_3

was reduced to almost zero. At the same time, it remained statistically significant for global students and the whole group.

These results clearly show that the predominant learning style for each of the four dimensions affects the level of cognitive load of the respondent. However, not always the Felder-Soloman learning style can be broken down into its components [20]. Moreover, essential indicators such as success and progress in learning chemistry depend on the complex impact of combinations of several individual styles [41]. Therefore, a possible role of style combinations should be investigated to expand the existing correlations between learning styles and data format-induced cognitive load.

4. Discussion

4.1. Consistency between the level of student expertise, task complexity and cognitive load

The approach of W. Schnotz [46] was used to visualise the effectiveness of teaching methods. The results indicate the need to adapt teaching methods to individual characteristics of trainee student groups. To be effective, the teaching methods and the complexity of the task for students must correspond to the students' perceptions. The task should not be too difficult. Otherwise, the internal load will overload the student's working memory. However, it also should not be too easy.

Figure 4a illustrates the theoretical approach to the possible adjustment of the inconsistency of students' level of expertise with the complexity of the task. The OX axis reflects the complexity of the task, and the OY axis - the level of expertise (training) of the student. Points located on the diagonal or close to it show a well-balanced learning process. In this case, the level of students' knowledge corresponds to the complexity of the task.

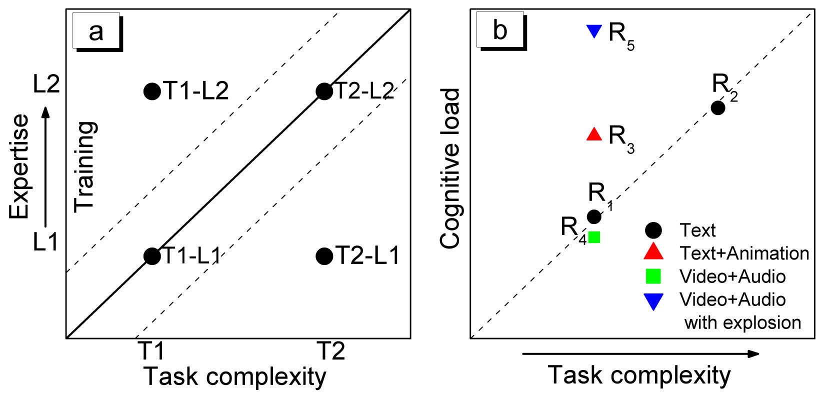

Figure 4. Consistency of complexity of tasks and students' expertise (a - adapted from [46]), correlation between task complexity and cognitive load when using different formats of information presentation (b).

The teacher's participation in the learning process, namely the provision of additional instructions, answers to questions, etc., helps reduce the load on students and increase expertise [46, 47]. Therefore, it is correct to talk about the interval that reflects a balanced learning process in terms of the scheme under consideration. This interval is symbolically limited with two dotted lines in figure 4a.

Points located relatively far from the diagonal (interval) show learning situations characterised by inconsistencies between task complexity and student expertise. Two randomly selected levels of student expertise (low L1 and high L2) and two randomly selected levels of task difficulty (easy T1 and difficult T2) are shown in figure 4a as illustrations. Different levels of complexity of the task can be formed for various reasons (the content of the task and/or accompanying instructions; the form of presentation of educational data, namely interactivity, variety of forms, the need for their integration, etc.). Of course, different sources of complexity can take different forms. It is also apparent that expertise and task complexity are continuous variables, so the graph shows only two levels for clarity and simplicity.

As long as the student has a low level of expertise (L1), the examination and complexity of the task will be well-coordinated in the situation of solving easy problems (T1). The combination

L1-T1 illustrates such a situation on the diagonal in figure 4a. The solution of a complex problem T2 by a student with the level of knowledge L1 overloads his/her working memory. The combination T2-L1 is much lower than the diagonal line.

The training aims to increase the expertise and is illustrated by a shift of the position of L1 to L2 (figure 4a). For a student with knowledge level L2, the task of level T1 is too easy. The location of T1-L2 shows this well above the optimal diagonal. Students with a high level of knowledge (L2) need more complex tasks (T2) for the optimal load. It is represented by the combination T2-L2, located on the diagonal. When the student's expertise and the complexity of the task are well aligned (T1-L1 and T2-L2), the student should deal only with the internal load. If not - an additional extraneous load is generated, which consumes the student's cognitive reserves.

Such inconsistency exists in two varieties. The first is shown by the area below the diagonal in figure 4a. It illustrates a situation when the complexity of the task exceeds the expertise or the instructions for the task are too complex (T2-L1). In this case, some students will most likely be overloaded with a too complicated task. The area above the diagonal visualises another type of mismatch. It shows a situation when the expertise exceeds the complexity of the task (T1-L2). In this case, some students waste time and energy processing unnecessary information or solving too simple tasks. Such a situation does not develop the cognitive abilities of such students; it has minimal learning functions.

Figure 4b illustrates the effect of different forms of representation of a chemical material (i.e. the type of electronic resource) on the dependence of the degree of cognitive load (R_n in all five experiments) as a function of the task complexity. If the resource type is not changed (reading the text), the load increases proportionally with the increasing complexity of the task (text). With the same complexity of the task (assimilation of information containing the text of the same complexity), as shown by the experiment, the load increases with the complexity of the form of presentation of material (with the appearance of animation and distracting sound and visual effects).

The coordinates of figure 4b are chosen to be as similar as possible to the coordinates of figure 4a. Comparing figure 4a and figure 4b, we see that the complexity of the form of presentation of information contributes to the growth of cognitive load. As a result, it requires a higher degree of expertise from students to master the task of equal complexity. Obviously, this violates the results of mastering the material in a group of students. Thus, an excessive complication of the form of presentation of chemical information not only does not simplify but, on the contrary, complicates its perception.

4.2. Consistency between the level of student expertise, task complexity and cognitive load

The use of ICT for the static image of multimedia objects is not fundamentally new in didactics. The literature thoroughly discusses the methods of reducing cognitive load when working with static images and multimedia presentations. The conclusions of scientists have correlated with each other and, in most cases, are definite. The technology of creating multimedia presentations considering the basic principles of the modern theory of multimedia learning is carefully described in the literature [48, 49, 50, 51]. The following is a brief list of recommendations for creating optimal presentations (table 5).

It is possible to reduce the external load when working with slides if:

a) provide audio rather than written text support for the screen image;

b) if necessary, place the image and text on one screen next to them; the text should be presented concisely;

c) provide for consideration of the image and stories about it simultaneously, not sequentially;

d) not to allow an excessive number of elements that the student must perceive simultaneously;

Table 5. Principles of slide design that do not cause cognitive overload.

Principle name	Description
Segmentation	It is necessary to divide the content into acceptable fragments because people learn better in small segments
Signal	The title should briefly reflect the main idea of the slide Modalities One needs to reduce the amount of text for visual perception; it is better to replace a part of the text with an image
Multimedia	Use visual images and words instead of just words
Sequences of presentation	One needs to remove all items that do not support the main idea of the slide

e) remove all unnecessary words, pictures, sounds: there should be no flickering, colour changes for elements that are not semantic accents;

e) place the elements on the slide to avoid the complication of perception (for example, to minimise the inscriptions on graphs and charts, etc.).

4.3. Factor analysis

The Felder-Soloman model considers the learning profile as a specific combination of four individual styles at once. A large number of components significantly complicates the analysis of their combined action. Therefore, we used factor analysis to identify hidden factors that explain the structure of correlations within a set of source variables. Factor analysis is often applied to reduce data dimensionality to find a few factors that explain the bulk of the variance observed for a much larger number of explicit variables.

The tendency of respondents with a specific combination of learning styles to use one of the three data presentation formats exploited in experiments 1, 3 and 4 were investigated using factor analysis. Table 6 illustrates the cumulative percentages of the explained variance for each of the six analysed groups.

Table 6. Cumulative percentages of the explained variance by groups, %.

Factor	$R_4/R_1<1$	$R_4/R_1>1$	$R_4/R_3<1$	$R_4/R_3>1$	$R_3/R_1<1$	$R_3/R_1>1$
1	33.385	46.678	35.550	55.643	44.734	46.393
2	59.225	72.128	62.761	81.617	78.697	69.593
3	83.119	97.074	83.970	92.038	94.215	87.056
4	100.000	100.000	100.000	100.000	100.000	100.000

The relationship between R_j and R_i for each of the three pairs was considered, namely R_1-R_3, R_1-R_4, R_3-R_4. If the ratio $R_j/R_i < 1$, then such respondents formed a group in which the load recorded in experiment i outweighs the load of experiment j. Conversely, if $R_j/R_i > 1$, then the respondents experienced a higher load in experiment j than in i.

The influence of all individual learning styles can be reduced to 2 newly calculated factors. Each of them, in turn, is a linear combination of several Felder-Soloman styles. When the dimension of the system is reduced, part of the data is lost. As we can see (row 2 in table 6), the proposed reduction of the dimension to two factors ensures 60-80% of the original information on the existing correlations between individual learning styles.

The factor analysis results by the method of principal components with Varimax rotation are shown in figure 5. They can be used to understand better the existing correlations between students' preferences in the format of information presentation and their learning styles.

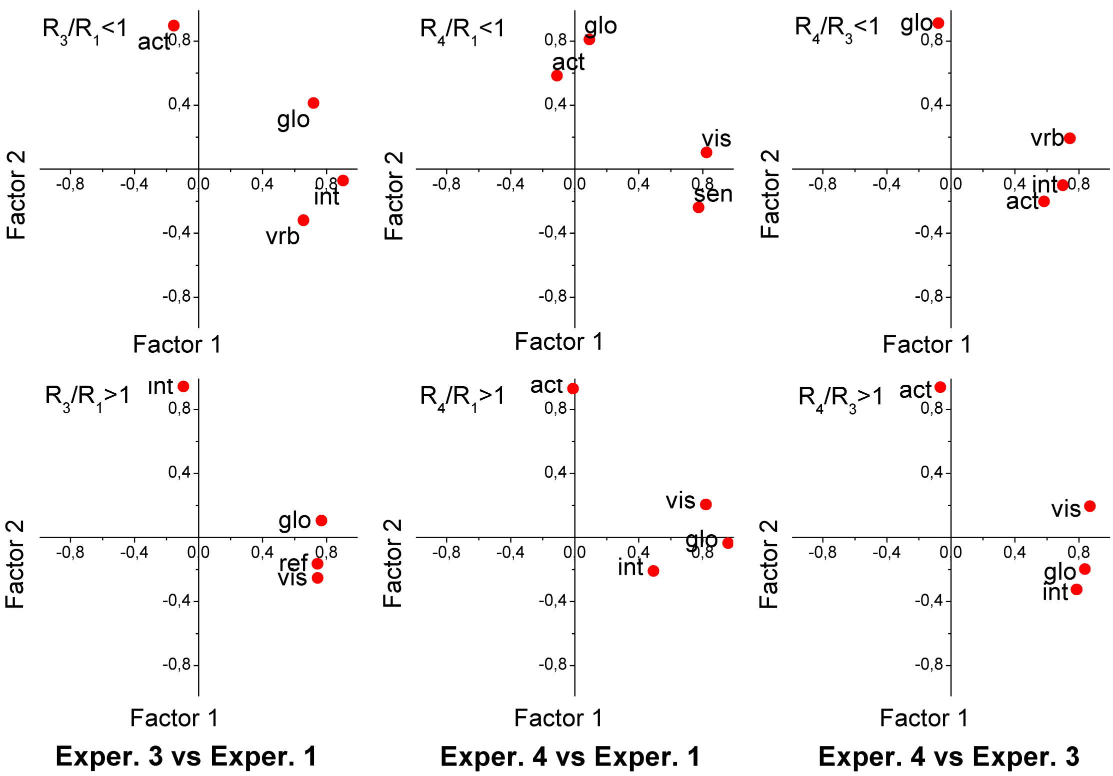

Figure 5. Reducing the dimensionality of the Felder-Soloman learning style system according to factor analysis results. Influential factors in inverse space for subgroups $R_j/R_i<1$ and $R_j/R_i>1$ formed by the results of experiments 1, 3 and 4.

For example, consider two diagrams in the right column in figure 5. A chart for respondents who better perceive information in the form of video + audio (experiment 4) compared to the text with animation (experiment 3) is located at the top of figure 5. Below is a diagram for respondents with opposite preferences ($R_4/R_3 > 1$).

The calculated factors are based on the same individual learning styles, with one exception. If the verbal learning style is essential in the upper corner, the visual style forms factor 1 in the second case. In addition, in the first case, the act style creates a more influential first factor, while in the second case, this style goes to the second factor to replace the glo style.

Let us compare experiments 1 and 3, where the difference in load was the largest compared to the other two considered pairs. Differences in two dimensions, namely vis-vrb and act-ref, are observed comparing experiments 1 and 3. Respondents who work best with text (bottom diagram, left column) have factor 1, formed with vis and ref styles. In contrast, respondents who prefer to work with text and animation (upper chart, left column) form factor 1 with the participation of the vrb style. The act style, which replaces the ref style on this diagram, forms the basis of factor 2.

Evidently, other factors, such as students' prior knowledge, computer experience, teacher quality, gender differences, may affect the results of experiments. We deliberately limited the scope of the study to show the need to predict students' cognitive load when using electronic resources. The use of the developed software makes it possible to control the cognitive load, mainly focusing on the distribution of students in the group according to their learning preferences.

5. Conclusions

The level of students' cognitive load, which arises in studying certain sections of organic chemistry using electronic resources of different types, was investigated. All 3rd-year students of the Faculty of Chemistry took part in the experiments - a total of 49 people. A multimedia textbook was used to compare the impact of different electronic resources. In particular, the chemical material was presented using texts of different complexity and different combinations of texts, audio, and video files.

Homemade software was developed and used to quantify the level of cognitive load. The secondary method was used in the development. Simultaneously with mastering educational materials in different formats (reading text, watching videos and listening to audio), respondents were periodically ordered to perform a secondary task (click on the button when changing its colour). The faster the secondary task was performed, the less workload the respondent experienced. Each student took part in 5 experiments, mastering the chemical material presented using different combinations of electronic resources. Accordingly, the most negligible cognitive load was caused by simple text. The highest is a video with audio, accompanied by sharp sound or visual effects (flashes and the like). On average, the highest-to-the-lowest load ratio is approximately 2.2 for the student group.

The Felder-Soloman Index of Learning Styles was used to determine the preferred styles for each student. Correlations have been established between the preferred learning styles of students and the cognitive load they experience while working, depending on the type of resources. The connection is quite complex. The factor analysis with an orthogonal Varimax rotation and Kaiser normalisation reduced data dimensionality. It revealed a few new hidden factors built on combinations of the learning styles. The two most influential new factors explain 70% to 80% of the sample for all resource combinations. However, the nature of the influencing factors is not stable and depends on the type of resources used.

The invented patterns between learning preferences and types of electronic resources will help analyse the effectiveness and development of teaching methods. By combining educational resources designed to consider the psychological and pedagogical aspects of knowledge perception, the teacher can optimise students' learning activities and improve the quality of learning.

A promising area of further research will be studying changes in cognitive load when using other combinations and types of resources. For example, learning with the help of dynamic visualisations, simulations of human movement, realistic or abstract images, etc.

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Visualizing the school organic chemistry course with augmented reality

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Abstract. Nowadays, studying natural sciences, as well as chemistry, is impossible without good-quality visualization of the theoretic data. Supplying mobile apps with augmented reality give the opportunity to visualize the study information for the students and make its perception and learning easier. The paper is dedicated to developing a lap book and mobile app LiCo.STEAM Sugar with augmented reality and studying the "Carbohydrates" topic according to the 10^{th} grade chemistry program, and also to investigate it's efficiency within the chemistry lessons. The developed lap book includes the theories with carbohydrate molecules' images, an experimental part designed for performing chemical experiments and studying properties of organic compounds, and also tasks of different levels. Molecules of carbohydrates, their structure can be visualized with AR, and also video-experiments on this subjets can be played. Using the lap book "Carbohydrates" with augmented reality together with LiCo.STEAM Sugar mobile app allows to upgrade the content and the volumes of the theories, apply modern ICT within the study in order to build students' skills of a new level. Applying educational data with augmented reality give students the ability to memorize the theories in a better way, which is shown with the increased results of educational achievements of students in chemistry.

1. Introduction

1.1. The problem definition

Creative, analytical, innovation thinking, the team project work abilities, information literacy and effective information and communication technology (ICT) skills – this is not the full list of responsibilities of a successful modern person [1, 2]. The nowadays students need the comprehensive training in various different natural disciplines, engineering and technology. That is why STEM-education has become so vitally important. The main advantage of STEM-education is the complex integration of inter-discipline approach units with the project study that combines natural sciences with technology and engineering. Practically, all the gained knowledge and skills are interdependent and integrated into one single unit [1, 2]

One of the key factors of the nowadays education is building the child's "individual study" skills. The new-era child needs not so much knowledge, but what they do need is to think consequently and critically, they need the intellectual activity [3, 4]. The content and methods of education in school are designed to develop education, memory, creative thinking, to build the comparing skills, to define specific characteristics of subjects, classify them according to specific features, and get delighted in finding a solution. When the children themselves co-operate with the objects studied, they investigate the environment in a better way. That is why, while working with children, practical methods should be prioritized [3, 4]. For this reason, the tutors face a challenge of searching new unorthodox forms of cooperation with their students. Traditional study is changed with the productive one, which is designed to develop creative skills, to provide the curiosity for creative activities. One of the perspective approaches, which expedite solving this problem, is lap booking [3, 4].

We should keep it in mind, that natural sciences are mostly experimental. Memorizing natural science knowledge effectively, and after that memorizing physics, chemistry, geography and astronomy depends not only from the theory supply form, but also from realizing the experimental part (practical activities and laboratory experiments), which require proper theoretic training both for the teacher and for the students.

The up-to-date school chemistry course is integrated, which is evidenced with the list of main responsibilities. The present information and communication awareness leaves no doubt that good quality chemistry learning is supplied only with modern information technologies. There are a lot of professional chemistry software packets (chemical reaction simulators, virtual chemistry laboratories etc.) on the new-era IT market [5, 6]. The contemporary ICT trends are virtual reality (VR) and augmented reality (AR), integrated with mobile education.

In the digital era, especially nowadays, under the national pandemic circumstances, the whole study is fully or partially remote. In this case, information and communication technologies are critical, considering the fact that the main study tool for a present-day student is not a personal computer or a laptop, but a cellphone (Android or IOS). This is connected with the availability of cellphones, their convenience, and the huge amount of existing mobile application, which are not only easier to use, comparing to the computer programs, but also more powerful for their purposes.

The school chemistry course provides visualization of molecules in 3D, meaning AR technology is highly recommended. As far as the AR technology is multi-functional: it plays video-files, audio-files, images, 3D models, its appliance within the school chemistry course is pretty wide.

1.2. Research objective
The objective of the research is developing a lap book designed for studying "Carbohydrates" according to the 10^{th} grade chemistry program with augmented reality and investigating it's efficiency while studying organic chemistry.

2. Literature review
Developing a lap book is the new-era method of organizing the education activity. It develops creativity, perception and investigation of the new info, provides repetition and memorizing of the info, studied before, summarizing the knowledge and it is just an interesting type of corporate activity of the teacher and the students. It also includes a mind-game. With this being said, lap book is the final stage of the individual investigation work, which the student is doing when studying a specific subject. In order to fill out a lap book, the student needs to solve some tasks, make investigations, study the supplied material [7]. Creating a lap book helps capture and classify the learned material, and over-viewing it allows to refresh the completed subjects pretty quick. It allows both the student and the teacher to classify the subject theories and to understand and memorize the material in a better way. This is also a good way of replaying the learned info [3, 4]. In the cooperation with AR, lap book is an interesting interactive tool of study, which makes the teachers' work easier, visualizes the theories in good quality and boosts the students' perception level.

Augmented reality (AR) gives the opportunity to visualize any object to the max point (atoms and molecules, their correlations, equipment setups, technology processes etc.), meaning to convert 2D images into 3D and "make it alive" [8, 9]. Educational AR technologies boost the visual and contextual study, upgrading the study content to the point, when 80% of it is being memorized, comparing with the 25% received either by ear (classical lectures) or while reading [10]. Visualizing the study info makes it perception and memorizing easier. Descent demonstration data help better understand various processes and phenomena, structures of chemical compounds and mechanisms of their correlations when studying the basic chemical concepts. Usual 2D images of the traditional handbooks and schoolbooks do not give the full image of the key concepts of natural sciences: the spacial structure of molecules, physical processes, chemical reaction paths etc. The specifics of applying the AR into the chemistry educating process is defined in the following publications [11–13]. Particularly, the authors have claimed about these advantages of supplying this kind of technology:

- It is effective when studying imperceptible concepts (atom, molecule, chemical bonds etc.) [11];
- It has a positive impact on the students' curiosity and on the memorizing process [12,14,15];
- Accelerates the development of students' spacial intelligence, their ability to imagine and manipulate three-dimensional structures (molecules, crystal structures) [16, 17];
- Boosts motivation for studying chemistry [13, 17, 18].

Providing 3D models of molecules plays a significant role when it goes about the efficiency of studying organic chemistry [12, 19]. The authors [20, 21] emphasize on the efficiency of augmented reality for modeling chemical reactions, and, as a result, increasing curiosity for studying chemistry.

Furthermore, Su Cai and co-authors [16] claimed AR visualizing to have a positive impact on the students' understanding of the information, given in text form. This gives the idea that AR technology must be combined with the study content, which will include the text data as well, in the perceptible for the modern-age students grade.

3. Methods

A lap book, including the theories, tasks and image-markers for the mobile app with augmented reality was developed to study the "Carbohydrates" topic.

A free mobile application LiCo.STEAM.Sugar (powered by Android) was developed in order to visualize the chemical structure of carbohydrates and reproduce the laboratory experiment videos, which can be used both by the teacher and by the students to study the "Carbohydrates" topic. Augmented reality markers, designed for the AR technology, were developed [22] on the Vuforia platform; 3D objects (molecules of glucose, fructose, sucrose, starch and cellulose) were modeled [22] with the 3ds Max app, augmented reality objects were realized with the multi-platform tool, designed for developing two- and three-dimensional mobile applications Unity 3D.

4. Results and discussion

Using the lap book with augmented reality elements in a combination with the mobile application LiCo.STEAM.Sugar allows to perform renovation of the content and volume of the study data; apply new technologies while studying in order to develop high-level skills. The developed lap book provides the information according to the school chemistry program (10^{th} grade), about the below:

- Formula and molecular structures of glucose, fructose, sucrose, starch, and cellulose;
- Nutrition value of carbohydrates, the definition of fast and slow carbohydrates;

- Carbohydrates in food products,
- Their impact on the human body, consumption dose and consequences of overdosing;
- Methods of production and refining of sucrose from different stock material;
- Nutrition products, containing sugar;
- Interesting facts about carbohydrates.

For the purpose of building practical skills while studying this topic, they can perform the following experiments: analyzing the starch concentration of nutritive products, investigating starch concentration in cereal crops, identifying carbohydrates.

The 3D pictures of molecules of carbohydrates, learning which is required by the study program, give the opportunity to visualize the molecules of glucose, fructose, sucrose to the max point, "make them alive", develop and boost the students' spatial intelligence, and to give a deeper understanding of the study data, received by ear, which will boost its memorizing and building specific practical skills [19]. This method has much more advantages comparing to computer programs, as far as it gives the opportunity to visualize the lap book images no matter where the student is located (in class, during the city sightseeing, at home etc.) on the cellphone, and it does not require a computer or a laptop.

When a cellphone or a tablet with the uploaded app is pointed at a marker (see figure 1, 2, 3, 4, 5), the picture "becomes alive", the screen shows its three-dimensional model, which can be manipulated in different ways (inversion, zoom-in, view from different angles), for better understanding its structure, operation concept etc.

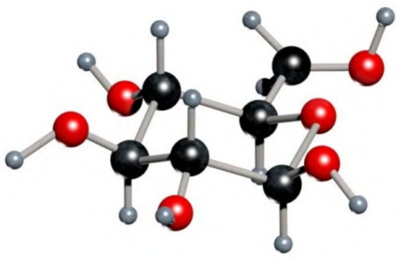

Figure 1. 2D image of glucose, located in the lap book, visualized with AR technology in the mobile app LiCo.STEAM.Sugar.

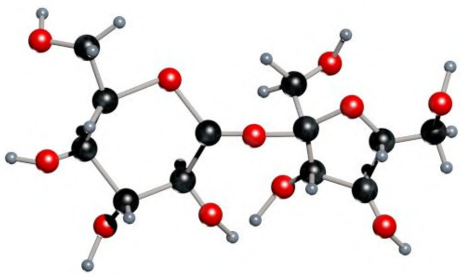

Figure 2. 2D image of sucrose, located in the lap book, visualized with AR technology in the mobile app LiCo.STEAM.Sugar.

Video-data of laboratory experiments investigating the concentration of starch in nutrition products, investigating starch in cereal crops, identifying carbohydrates were created for the

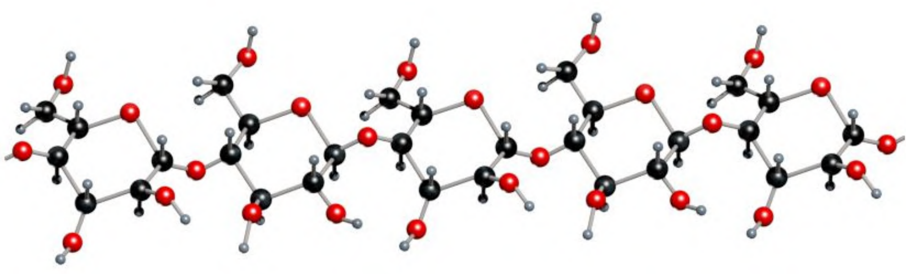

Figure 3. 2D image of cellulose, located in the lap book, visualized with AR technology in the mobile app LiCo.STEAM.Sugar.

purpose of supplying the experimental part. The developed videos are displayed on smartphones after "connecting" them with individual marker-images in the lap book.

The developed video-materials demonstrate laboratory experiments, performed by an experienced laboratory engineer, following all the safety regulations. The experimental performance is subtitled with text explanations. Using the developed video data give the student an opportunity (under the supervision of the teacher or parents) to repeat the same experiments in class or at home, makes the perception of this material much easier and the experimental part, too much complicated sometimes, is demonstrated understandably.

The figure 4 gives an example of one of the developed markers for the recommended laboratory experiments on the "Carbohydrates" topic, located in the lap book, designed for both teachers and students.

Vector images were selected as markers, they convey the context of the experiment, they are realized through a multi-platform tool, designed for developing two- and three-dimensional applications Unity 3D.

Also, the lap book "Carbohydrates" provides the setup of industrial production of sugar from sugar-beet, which every student can overview in AR. When the cellphone or tablet is pointed on the particular marker (see figure 5), an animation video is displayed on the screen (see figure 6).

Figure 4. "Marker", designed for reproducing laboratory experiments (investigating the concentration of starch in nutritive products), located in the lap book (visualized with AR technology in the mobile app LiCo.STEAM.Sugar).

In order to identify the curiosity of 10^{th} grade students in using the augmented reality and its efficiency during the chemistry lesson, students of vocational school N24 in Ivano-Frankivsk city took a survey. The survey was taken by 60 people.

The survey results show that each student has a personal mobile device that can be used for study. All the students have used mobile apps with AR within the study process, and 100% of

Figure 5. Marker, developed to display an animation video "Production of sugar from sugar-beet" (visualized with AR in the mobile app LiCo.STEAM.Sugar).

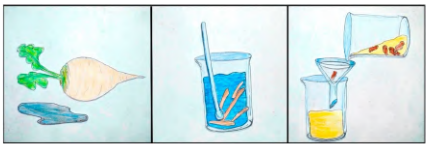

Figure 6. Animation video parts of "Production of sugar from sugar-beet" (visualized with AR in the mobile app LiCo.STEAM.Sugar).

the surveyed have confirmed the advantages, the technologies benefit in during the chemistry lessons. Furthermore, 83.87% of the surveyed think, these technologies would be efficient during other lessons. The survey results picture is shown on figure 7.

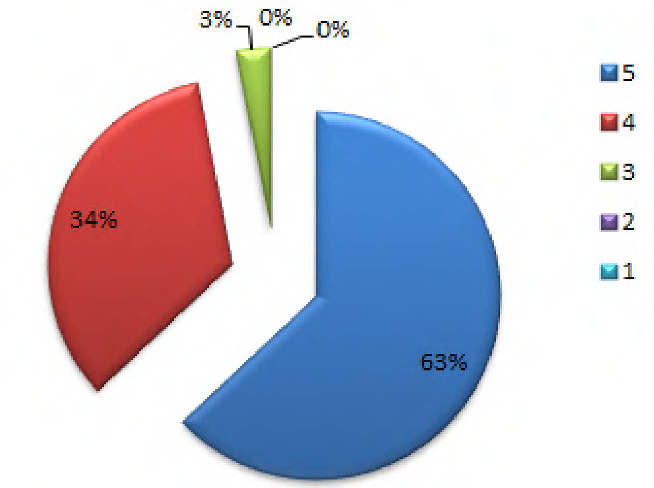

Figure 7. Efficiency rating of memorizing the study info, having used the "Carbohydrates" lap book and the mobile application LiCo.STEAM.Sugar during the chemistry lesson; marks from 5 to 1 (5 – it boosts the memorizing a lot, 1 – it is useless).

For the purpose of investigating the efficiency of using the developed mobile application and lap book during the chemistry lessons, a comparative analysis was made on the subject of students' educational achievements (two quiz-tests). They compared the achievements with the lap book and without it. The quiz was answered by 10^{th} grade students of high school N24 in Ivano-Frankivsk city. In order to realize the experiment, the students were divided into two model groups:

I. Group (30 students, with 11 high-level students, 12 – medium-level, 6 – sufficient, 1 – low):
   A) While studying the theory and preparing to the quiz N1 they were using the "Carbohydrates" lap book combined with the mobile application LiCo.STEAM.Sugar

Journal of Physics: Conference Series **2288** (2022) 012017 doi:10.1088/1742-6596/2288/1/012017

The quiz was performed by the students on separate sheets of paper after short guide speech of the teacher.

B) While preparing to the quiz N2 and studying the theory, the lap book was not used. The group performed the quiz on separate sheets of paper after short guide speech of the teacher.

II. Group (30 students, with 10 high-level students, 12 – medium-level, 6 – sufficient, 2 – low):

A) While studying the theory and preparing to the quiz N1 the lap book was not used. The group performed the quiz, like group I, on separate sheets of paper after short guide speech of the teacher.

B) While studying the theory and preparing to the quiz N2 they were using the "Carbohydrates" lap book combined with the mobile application LiCo.STEAM.Sugar The quiz was performed by the students on separate sheets of paper after short guide speech of the teacher.

The calculation results are given in the table 1.

Table 1. The investigation results on efficiency of the developed mobile device and lap book during chemistry lessons.

Criterion	Group I		Group II	
	A (Lap book with AR)	B	A	B (Lap book with AR)
Average mark	8.21	7.00	7.15	8.07
Education achievement rate	84.61%	61.54%	50.1%	78.57%

Investigating the subjection of the experiment results to the normal division law showed [23], that the normal division law of students marks does not contradict with the results, received after the individual quiz.

In order to investigate the hypothesis about equality of common marks H_0: m_1=m_2 the t-criterion was being calculated, according to which a conclusion was made about statistic inequality of common marks among the students of groups I and II with the significance value α=0,05:

$t_{cI} = 2.00; t_T = 1.68; t_{cI} > t_T;$

$t_{cII} = 1.78; t_T = 1.68; t_{cII} > t_T.$

The results of this experiment in table 1 conclude that the lap book with the mobile app LiCo.STEAM.Sugar benefits in better perception and reproduction of the students' knowledge and achievements. The students, using the lap book "Carbohydrates" integrated with the mobile app LiCo.STEAM.Sugar while studying the theory, had higher results, which is confirmed with the increase of education achievement rates.

As a conclusion, the students using the lap book with augmented reality elements in a combination with the mobile application LiCo.STEAM.Sugar for study achieved better results:

For group I: the quality has a 23.7% increase, the average mark is 1.21 higher (according to the absolute value).

For group II: the quality has a 22.47% increase, the average mark is 0.92 higher (according to the absolute value).

In fact, the students had to be very attentive while performing the practical works and laboratory experiments in chemistry, observing the real experiment. If a particular action of the

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teacher or the student, performing the work, was missed it would be re really hard to recover the sub-sequence of the whole reaction mechanism. The student does only see the final result, missing the intermediary steps, which are also important in order to do some calculations and build conclusions, which influences the perception quality. In order to address these issues of the studying process integrated with the chemical experiment, mobile apps with AR are the remedy, as far as they allow to repeat the missed theories, overview it again, expand separate stages of the process individually etc.

5. Conclusions

Providing mobile education technologies not only lift study to a new level, supplying the users access to knowledge 24 hours a day with no matter where they are, but also give wide opportunities for the students.

A lap book and a mobile app (on Android) was developed in order to visualize the chemical structure of carbohydrates and playing video-files of laboratory experiments and 3D models of molecules, which can be used both by the teacher and the students for an effective "Carbohydrates" drill in organic chemistry in the 10^{th} grade.

Reviewing the molecule images in 3D give the students an opportunity to understand the structure of organic compounds, predict their properties and realize mechanisms of their correlations. Video-experiments, reproduced with AR, help students prepare for performing a chemical experiment and perform it properly, according to all the health and safety regulations. This complex approach to studying the organic compounds' properties advantages in better memorizing the theoretic info, which is shown by increasing the perception quality value among the students and the common chemistry mark.

Combined with the augmented reality, the lap book gives the ability to improve understanding of the theory, expand and illustrate it, which boosts the perception and development of creative intelligence of the students, as well as increases the level of memorizing and reproduction of students' education achievements.

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The use of augmented reality in chemistry lessons in the study of “Oxygen-containing organic compounds” using the mobile application Blippar

The use of augmented reality in chemistry lessons in the study of "Oxygen-containing organic compounds" using the mobile application Blippar

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Abstract. A training kit has been created to study the topic of "Oxygen-containing organic compounds" using augmented reality. We chose the Blippar platform to work, it is quite simple and relatively free. The kit contains markers we have developed, on which, with the camera from the Blippar application, students will be able to observe thematic experiments and molecules of individual substances with the help of augmented reality. There was also a study on the effectiveness of our developments to implement augmented reality in the course of chemistry. The study results showed an increase in pupils' motivation to study chemistry and their level of interest, facilitating the perception of the theoretical foundations of organic chemistry related to the spatial structure of molecules. Also, the use of augmented reality technologies creates the conditions for improving the level of digital and technological competencies of students, provides support for high quality teaching of chemistry in distance learning.

1. Introduction

In the current situation caused by the COVID-19 pandemic, most educational institutions have been forced to switch to distance learning, which has been a major blow to untrained teachers. This was especially true of subjects with certain specifics in the organization of the teaching process: chemistry, physics, biology, astronomy, and so on. The use of augmented reality significantly increases the effectiveness of distance learning, allows teachers of natural sciences to teach quality teaching materials using the necessary visual aids, and the ability to conduct laboratory and practical work remotely [1] [2].

You can find schools that due to certain circumstances do not have the necessary equipment and reagents for quality work provided by the program. In this situation, you can also turn to AR technology, and give students the opportunity to get acquainted and learn to work with the necessary equipment, even in its absence. The urgency of the topic of the work is due to the high demand for AR applications and the rapid development of technologies, the potential of which has not been fully explored yet [3].

Acquaintance with the topic "Oxygen-containing organic compounds" in the program profile training takes place after learning such lessons: "Theory of structure of organic compounds", "Hydrocarbons", "Heterocyclic compounds" and "Natural sources of hydrocarbons and their processing".

Throughout it, the topic, the content of theoretical material should be accompanied by practical activities. The curriculum of the discipline provides for laboratory experiments, demonstration reactions and practical work. According to the recommendations of the Ministry of Education and Science Ukraine for the profile level of studying chemistry at school in the topic "Oxygen-containing organic compounds" should be conducted 3 practical works, 5 laboratory experiments and demonstrated at least 18 demonstration experiments. The use of such forms of work allows to study the chemical and physical properties of the compounds for study. In addition to the use of the above forms of work, students are also expected to complete educational projects [4].

The number of augmented reality applications in chemistry lessons adapted for use in Ukrainian schools is insignificant. The most popular are:

- LiCo - a mobile application that can be used only for Android gadgets [5]. This program is a striking example of augmented reality based on markers. In this application it is possible to reproduce videos of practical work and laboratory experiments in accordance with current programs in chemistry for secondary schools. The main advantages include the possibility of acquainting students with the course of practical work, or an example of a home experiment. To get started, simply open the downloaded program and point its camera to the appropriate marker. Another advantage is the intensification of cognitive activity, which allows you to theoretically master certain rules for the use of chemical utensils and the basic techniques of working with it, stimulates creativity. The main drawback is the technical failures of the application, as well as problems with the playback of some videos [6] [7].
- LiCo.Organic - a mobile application that can be used only for Android-based gadgets [8]. This application is used to study organic chemistry, namely it allows you to translate 2D images into three-dimensional in augmented reality, giving students the opportunity to look around the structure of the molecule of many organic substances. To work with the application, simply open the program downloaded to the phone and point the camera at the marker, after which the molecules of the compounds will appear, represented in the form of spherical rod models. The main disadvantages of this program include incorrect operation and frequent failures in the process of working with the program [9].
- LiCo.STEM is a mobile application that can only be used for Android gadgets [10]. The application is designed to introduce educational systems and works in conjunction with a laptop. The application paired with laptop allows you to see structure of water molecules, ice, steam just on your desktop. This way of perceiving information promotes better learning and allows you to consider in detail the structure of water in different physical states [9].
- QuimicAR - a mobile application that can only be used for Android gadgets [11]. This program is a beta version, but it is already possible not only to reproduce 3D-models of molecules, but also to be able to see the direct course of the reaction. To work with the program, it is enough to install the application and guide the camera for the appropriate marker, and to view the progress of the response, several markers were used, which will be delivered nearby.

The applications listed above are free.

Bippar - a mobile application that can be used for gadgets based on Android and iOS [12]. Using this application is very easy, just point the camera of the included application on the appropriate marker. An indisputable advantage is the ability to create your own marker and model that will be displayed during use. In addition to 3D models, you can add videos, regular 2D images, text and audio files for viewing, which allows the user to reproduce what they see on any surface.

The use of such a tool of ICT in the study of new material provides an opportunity to improve students' spatial imagination, "see" and better understand the learning material, which will contribute to better learning and the formation of certain practical skills [13]. From the augmented reality platforms and applications discussed above, we chose to work with Blippar.

2. Methods

Given the active development of augmented reality technology in education, we also tried to join the creation of AR materials that could be used in chemistry lessons, namely in study the topic "Oxygen-containing organic compounds". Based on the experience of previous researchers, we decided to use the marker type AR. Analyzing the already known experience, we can conclude that for the correct operation of the marker you need to follow some rules when creating it.

Basic requirements for the marker:

- sufficient content of information;
- ease of use;
- clear orientation;
- high quality and sharpness of the image;
- versatility of materials.

When designing the markers that we plan to use to display augmented reality objects, we first had to think about the end user, because success depends directly on a clear understanding of the purposes of use, the preferences of tenth-graders in our case.

During the work we had two options for the end result. The first option was to create a more classic black and white marker, the second option, ie the one we chose, is to make them bright and interesting to attract the attention of students.

We have chosen to follow one style, in which we have developed twenty markers, five of which for laboratory experiments, three for practical work and twelve for displaying 3D models.

We created all the markers using Microsoft Paint, and we found additional images used on the markers using the pinterest.com site.

We would like to offer to consider some of the markers we have created (figures 1-2).

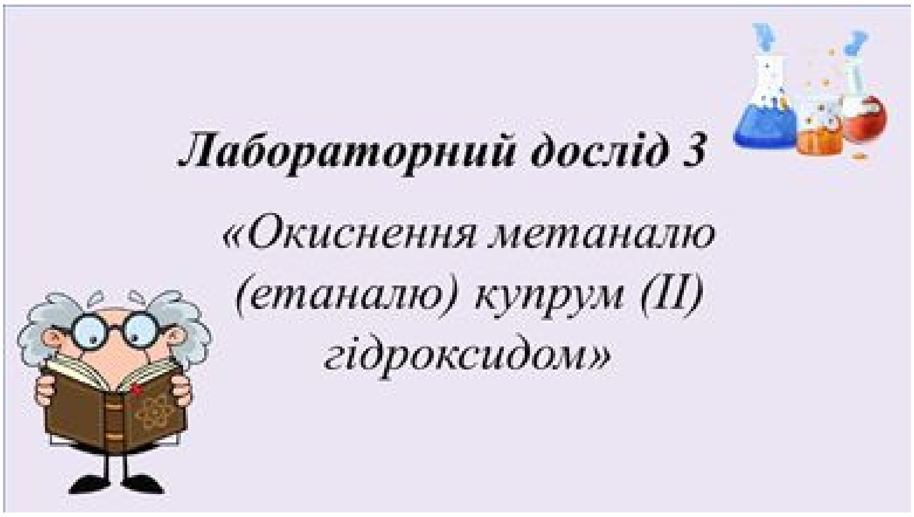

Figure 1. Example of a marker developed for a laboratory experiment "Oxidation of methanol Copper(II) hydroxide".

We decided to combine all our own markers into one kit for reproducing augmented reality on the topic "Oxygen-containing organic compounds", which can be found at https://goo-gl.me/Hazhs.

The program in the topic “Oxygen-containing organic compounds” provides for the performance of five laboratory experiments and three practical works. We decided to create videos for them based on the textbook on chemistry of the profile level [14], namely: laboratory experiment 3 “Oxidation of methanol (ethanol) by copper (II) hydroxide”, laboratory experiment 4 “Oxidation of alcohol to aldehyde”, laboratory experiment 5 “Ralation of oleic acid to bromine water and potassium permanganate solution”, laboratory study 6 “Solubility fats in water and organic solvents”, laboratory experiment 7 “Oxidation of glucose by copper (II) hydroxide”, practical work № 4 “Solving experimental problems”, practical work № 5 “Synthesis of ethylethanoate”, practical work № 6 “Solving experimental problems ”.

Figure 2. Example of a marker designed to demonstrate a 3D model of molecules (glycerol).

Due to the lack of some reagents, we had to use several experiments that have already been filmed by other people. We borrowed the video from YouTube video hosting [15] [16].

After recording the video of all the necessary experiments, we moved on to the next step of our work, which was to edit the footage and turn it into a full-fledged laboratory and practical work. To do this, we used Windows Movie Maker.

At the editing stage, we decided that it would be more appropriate to make the final video without audio, as there are several ways to use it, namely when using our development during the lesson, when it will be used by all students in the classroom audio will be superfluous. Nevertheless, we consider it necessary to explain what is happening on the video, and we decided to get out of this situation by commenting in writing.

This solved another problem, namely reducing the video time, because to watch it in distance learning video duration, for example, practical work of 10-15 minutes is appropriate, and if our development is used directly in the classroom lasting 45 minutes it is desirable to reduce the time required to watch the video, which we did.

Another task we set ourselves is to create a 3D model of some organic compounds, for which there are several ways. The first is to load a ready-made model, and the second way allows you to create a model directly in Blippar. We chose the second way.

The first step in creating an augmented reality tool is to register on the developer’s website (https://www.blippar.com/). The next step is to create your own project (‘Create an App Project’), and create your own marker, for which you must select ‘Start from scratch’. Next, you need to choose a picture that will serve as a marker, for which we select ‘Browse’ in the window and look for a previously saved image on your device (see figure 3).

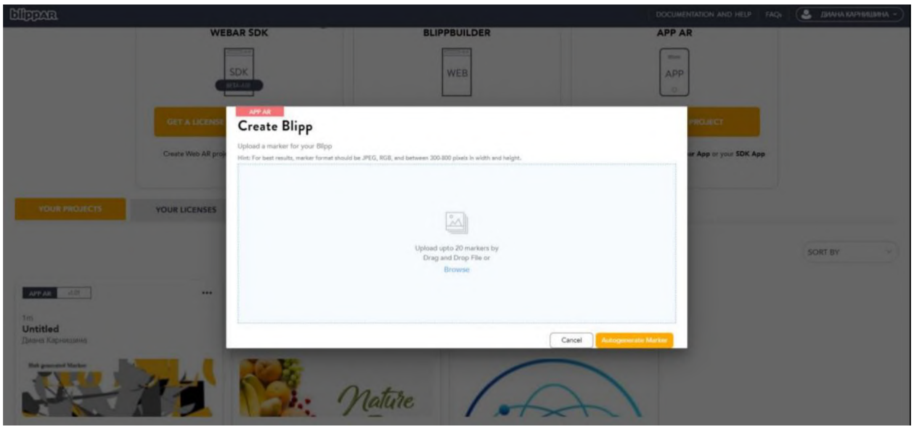

Figure 3. Create a marker in the Blippar application.

After these steps, a scene appears where you can place the objects that will be displayed when you hover the camera of the mobile application on the marker. The interface of the program is quite simple: on the right side there are properties of the scene that can be adjusted, and on the left side in the tab 'Elements' there are elementary versions of 3D figures that can be placed on the scene.

We used balls of different colors to denote atoms, and cylinders to denote chemical bonds. The program allows you to change the parameters of the basic shapes, as well as place them at any angle in space.

Equally important is the ability to rotate the scene at any angle, or see the view of the molecule from different sides, by clicking on the image of a square with four arrows in different directions, which is to the right of the scene (selected in figure 4).

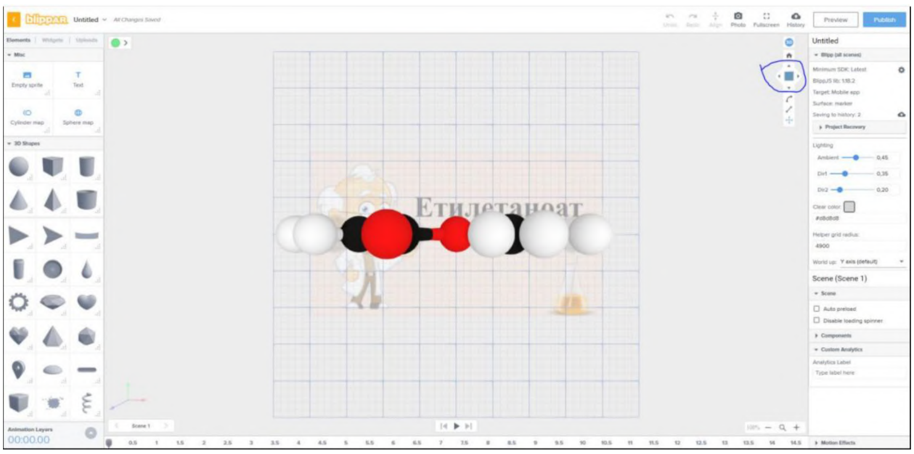

Figure 4. Creating a 3D model in Blippar.

It is also possible to download your own or pre-downloaded 3D models from the Internet (required in fbx-format).

There are several options for adding video. First: adding video using the 'Widgets' → 'Video' section, using it we can use video links or insert videos into the program. Using the open 'Video' tab, you can adjust the location of the video on the scene, select the image that will be used for the screen saver, and choose how to download the video. Second option: go to the 'Widgets' section and select YouTube from the prompts by dragging it to the scene. In a separate tab, you can change the video playback settings, and choose how the video will be launched (directly in the program or from YouTube video hosting).

When all the objects are added, you can save the project - click the preview button in the upper right corner. A new window opens, in which you are asked to create your own access code for the project or use the proposed one, then click continue. In the next window we will see a record of our code and a marker, which will display the elements of augmented reality created by us. Then click publish to test and the project is published, which we can now view using the mobile phone on which we previously downloaded the mobile version of the application Blippar.

There are two versions of Blippar: free and paid. The principle of operation of these versions is somewhat different. In the paid version, just point the camera from the mobile application to the marker and immediately see the result. When using the free version, you have to perform one additional action - in the upper left corner, click the settings icon and in the window that opens, select 'Enter code' and enter the access code that was created during project development. Then click 'Confirm' and you can point the smartphone at the marker, then click the icon at the bottom of the screen labeled tap to scan. When the marker is read, we can move the projection to any surface convenient for us and also have the ability to move all objects in space.

We used the free version of the Blippar app.

3. Discussions

Analyzing the research already conducted on the benefits of introducing elements of augmented reality in the educational process, we can identify the main points that show that AR in education [17]:

- make learning easy;
- motivate to study;
- concretize abstract concepts;
- contribute to the development of abstract thinking;
- increase interest in learning.

After the introduction of our developments in the educational process, a survey was conducted to analyze the effectiveness of the use of technology among 10th grade students, which included the following open-ended questions:

1. Have you heard of augmented reality before?
2. Have you ever used augmented reality elements during the educational process?.
3. Did you enjoy using augmented reality elements in chemistry lessons?
4. Do the elements of augmented reality help in the development of complex material?
5. Does the use of augmented reality technology increase your motivation to study chemistry?
6. Did you use Blippar outside of the lesson?
7. What exactly did you enjoy in the augmented reality lesson?
8. For what purposes did you use Blippar outside of the lesson?

The analysis of the survey results is presented in the form of diagrams (figures 4-9). 65 students took part in the survey.

Looking at the resulting chart on "Have you heard of augmented reality before?" can see the following statistics: 60% of students already had an idea of augmented reality; 20% of students had never heard of AR; 20% of students are not sure that they are familiar with this concept (figure 4).

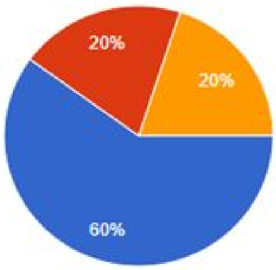

Figure 5. Diagram of answers to question № 1(blue – yes, red – no, yellow – perhaps).

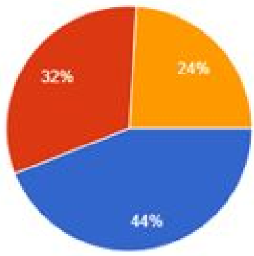

Figure 6. Diagram of answers to question № 2 (blue – yes, red – no, yellow – perhaps).

After analyzing the results of students' answers to question № 2, which sounded like "Have you ever used elements of augmented reality during the educational process?" we have the following results: 44% of students say that they have already encountered the use of augmented reality technology in learning; 32% of students indicated that they were not previously familiar with AR during the educational process; 24% are unsure of their answer (figure 4).

Based on question № 3 (figure 6), namely "Did you like to use elements of augmented reality in chemistry lessons?" students' answers are unambiguous, we can see 100% answer yes.

Analyzing the answers to question № 4, which reads as follows: "Do the elements of augmented reality help in the development of complex material?" we can conclude that 96% of students our development helped to master the complex material, ie simplified it and only 4% of students are not sure of their answer (figure 7).

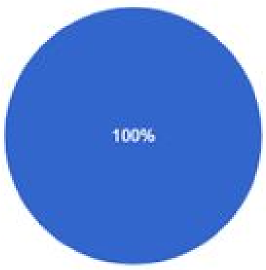

Figure 7. Diagram of answers to question № 3 (blue – yes, red – no, yellow – perhaps).

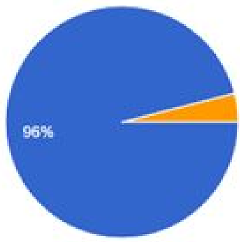

Figure 8. Diagram of answers to question № 4 (blue – yes, red – no, yellow – perhaps).

Looking at the results presented in question № 5 (figure 8), namely: "Does the use of augmented reality technology increase the motivation to study chemistry?" Again, we see such statistics showing that the use of augmented reality in the classroom increases motivation to learn in 96% of students, and only 4% of students gave a negative answer to the question.

Diagram of answers to question № 6 (figure 9), which reads as "Did you use Blippar outside of class?" illustrated the following picture: the majority of students, namely 56%, use our development outside of the lesson, which shows that it is really interesting for students; 36% of students indicated that they use the program only in class on the instructions of the teacher; 8% are unsure of their answer.

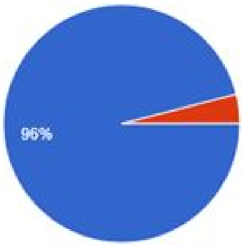

Figure 9. Diagram of answers to question № 5 (blue – yes, red – no, yellow – perhaps).

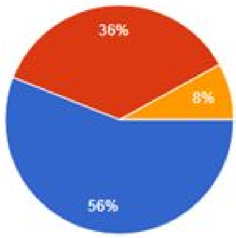

Figure 10. Diagram of answers to question № 6 (blue – yes, red – no, yellow – perhaps).

Analyzing students' answers to question 7, namely: "What exactly did you like about the lesson using augmented reality technology?" we can observe that the majority of students indicated that with the use of augmented reality the lesson became more interesting, abstract concepts became clearer and motivation to study the subject increased, students became more eager to attend chemistry lessons.

Based on the answer to question № 8, which was as follows: "For what purposes did you use Blippar outside of the lesson?", We can conclude that many students use our development outside of the lesson, namely to prepare for the next lesson, doing homework and just out of curiosity, in order to once again see and interact with previously inaccessible 3D objects.

Taking into account the above statistics, we can say that our development is interesting for students, can increase students 'interest in studying chemistry, simplify the explanation of difficult material, which in turn will improve the quality of students' knowledge and attitude to learning in general. For the teacher, the use of this technology also has many advantages, namely saving time in the classroom, there is an opportunity to demonstrate certain experiments that can not be done in reality due to certain circumstances. Work with students in the conditions of distance learning is simplified, because all the necessary material is already in one set created by us. There is also a great saving of teacher time, as there is no need to process videos found on the Internet and process them so that they help students to do the work you set.

Thus, we can conclude that the introduction of new technologies in the educational process, including augmented reality technology, has helped to reveal the weaknesses of traditional teaching methods, and is a great way to improve existing traditional systems.

4. Conclusions

The life of the modern student is influenced by new information technologies. Computer literacy and communicative education of students are competencies that are formed only in the application of information and communication technologies and provide a successful outcome in a wide range of educational activities.

The experience of using augmented reality technology in chemistry lessons at school shows that in order to obtain a high educational effect, it is important to use them systematically at all stages of lessons:

- actualization of basic knowledge;
- motivation of educational activities;

- learning of new material;
- generalization and consolidation of knowledge.

Successful use of information technology in combination with traditional teaching methods increases students' interest in studying chemistry, their activity, strengthens their desire to acquire knowledge independently. The lesson creates an atmosphere of cooperation, understanding and friendliness.

The Blippar platform, in our opinion, is quite simple to work with and allows chemistry teachers to use it in different variations to create additional methodological developments. The ease of working with the platform is that the teacher does not need to have special skills as a programmer. The markers created by us have been introduced into the teaching of chemistry in secondary schools. At the final stage of studying the topic "Oxygen-containing organic compounds" a study was conducted on the effectiveness of our developments in the implementation of augmented reality in the course of chemistry. The results of the study showed that the use of AR helps to increase students' interest in the subject, motivates students to actively study chemistry.

The use of augmented reality technology in teaching chemistry helps to develop students' spatial thinking and improve understanding of the structure of molecules of organic compounds.

It is also important to emphasize that the use of augmented reality technology helps to develop students' spatial thinking and promotes the harmonious development of modern personality.

The use of traditional methods of teaching chemistry is significantly complicated in the context of distance learning. Therefore, the use of augmented reality technologies provides an opportunity to further maintain a high level of cognitive activity of students and the opportunity to acquire relevant knowledge. This can be a good prerequisite for maintaining a high level of knowledge of students in organic chemistry in such unusual conditions.

Also the AR technology usefulity of for students with various congenital or acquired defects, who do not have the opportunity to attend school, and the teacher simply can not physically conduct a lesson at home demonstrating all the necessary visual material on this topic. Thanks to this technology, all students will be able to receive better educational material.

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PAPER • **OPEN ACCESS**

A Learner-Centered Syllabus-Based Approach to engaging master students into research activity

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A Learner-Centered Syllabus-Based Approach to engaging master students into research activity

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Abstract. This paper presents a vision of a team of researchers on solving a problem of engaging future Mathematics teachers into a research activity through implementing person-centred approach to learning and teaching. The authors of the given article present a designed Learner-Centered Syllabus of a training research workshop in Mathematical Analysis for Master students, majoring in Mathematics at teacher training universities. This study presents the structure, the components and the content of a Learner-Centered Syllabus. When giving content to the sections of the syllabus, the developers take into consideration the conditions for person-centredness; creating the atmosphere of acceptance and congruence; shaping in students the personal qualities, which contribute to their research activity; arranging collaboration; engaging students into the assessment process. The researchers in the present study identify orientation at self-development as a key concept of the course policy and make each section of the syllabus personal. The following sets of attributes were used to evaluate the designed Learner-Centered Syllabus: Community, Power and Control, Assessment and Evaluation. The experimental study was done over four years, two groups of Master students majoring in Mathematics became its participants. One group was given a conventional Content-Focused Syllabus of a training research workshop in Mathematical Analysis, while the second group received a Learner-Centered Syllabus, designed in accordance with the Person-Centered Approach to Teaching and Learning. The analysis of the findings of this experiment justified the efficiency of creating a learning environment, which is determined by the emotional components, such as Congruence, Acceptance and Empathic understanding. The present paper also shows a positive impact of the syllabus on the degree of students’ motivation to choose the training research workshop in Mathematical Analysis.

1. Introduction

One of the main tasks of teacher training is to develop in future teachers a research competency that can be used for further professional and academic growth. Thus, [1] consider a research learning activity to be one of the mechanisms of shaping the research competency in students, as doing such an activity helps to develop the core skills, corresponding to the stages of scientific research. This idea correlates with the conclusions by [2, 3], who state that these very skills are crucial for a successful academic career and professional development of a teacher.

According to a research by key European organisations-stakeholders, among which are the European Association for Quality Assurance in Higher Education (ENQA), European Students' Union (ESU), European University Association (EUA), European Association of Institutions in Higher Education (EURASHE), success in developing students' scientific activity depends on the choice of the learning strategy. Being currently at the core of the educational process, student-centred learning and teaching make this process more varied and able to meet the increasing expectations from higher education stakeholders, which is emphasized in the Standards and Guidelines for Quality Assurance in the European Higher Education Area. Thus, the issue of engaging future Mathematics teachers into a research activity through person-centered approach is becoming relevant and timely.

1.1. The analysis of the scientific studies

The importance of a research activity for training future teachers. The importance of a scientific research activity of students within the framework of formal and non-formal education has been largely debated in research papers. [4] stated that the students, who are engaged into doing research projects, show better academic results. [5] consider, that students' participation in a research activity contributes to establishing positive relationship between students and a tutor, such students are more orientated at academic career in future. [6] gives evidence that students, who join scientific laboratories at their universities, attend conferences and scientific seminars, have their papers published and have a broader learning experience. [7] state, that in higher education research is "the gold standard" in the context of academic activity.

Conducting a historical review of the key elements in the development of a research and teaching culture within the Department of Retailing and Marketing at the Manchester Metropolitan University, [8] focused on issues of research management, examining and evaluating the contrasting alternative approaches of staff development responsibility. The researchers put emphasis on maintaining synergy between teaching and research activity.

Scientists have also been engaged into searching the ways that help students to identify themselves as "proactive in research". [9] consider the issues of ageing scientific manpower and engaging postgraduate students into research activities in hard science. The current situation in the realm of Mathematics and Physics causes concern, so it is emphasized by the scientists themselves that the research activity of undergraduate students, majoring in Mathematics, not only contributes to their professional development as future teachers, but also ensures their further research activity in Mathematics and continuity of the scientific school.

The experience of introducing person-centred approach to arranging a research activity when teaching Mathematics. Shamai and Kfir [10] in their paper discuss the importance of a research activity in academic teacher's colleges in Israel. Indicating the main obstacles, that impede a research activity at colleges, the authors define the conditions that have a direct impact on the research performance. The researchers focus on developing models for a research activity that are based on introducing person-centred approach to learning and teaching. Puskur [11] also considers that person-centred models of teaching develop mathematical thinking that can satisfy currents and future needs in adapting to a constantly changing environment. According to [12] such an approach to teaching Mathematics leads to developing logical and critical thinking, creativity, ability to work independently, discipline, self-development, confidence; feeling the beauty of Mathematics and unbiased necessity to look forward, into the ever-changing future. [13, 14] show in their studies that lack of a teacher's attention to the personality of a student leads to their inability to understand the research process and absence of an alternative way of thinking, which would be different from the one, demonstrated by the teacher. In this case there is no informed understanding and the goals of a research activity are not achieved. Thus, the positive experience of the above mentioned researchers confirms the possibility to arrange the research activity of students through the application of person-centred approach to learning and teaching.

The experience of designing student-centred syllabi. The evolution of the concept of a personal-centred learning is reflected in various studies, among which are the papers by [14–18] and others. The researchers justify the relevance of designing student-centred syllabi and state, that compared with a conventional syllabus, it differs not only in content, but also in tone. It is believed, that there is a necessity to shift the focus from "What we have to cover" to "How will the course contribute to students' learning and their intellectual development". Hence, such a syllabus contains almost the same information as the conventional one, but its style and language, used for describing policies, procedures, the content differ greatly. A Syllabus-based Approach to learning and teaching was also of interest for [19], who emphasized on the fact, that a properly designed plan provides students with a road map for engagement and obtaining successful learning experience, creating a more positive learning environment. The researchers point out, that a syllabus which is not student-centred, hampers interaction between a tutor and students, increasing their level of anxiety and decreasing the total efficiency of the learning process. This idea was supported by the conclusions, made by [20], who consider, that the first impression which students have from the course syllabus, after learning it, is rather deep and lasts throughout the course. Therefore, it is critical to make a positive impression before the course starts, at the first stage of communication between a tutor and students.

[21–23] justify the necessity of designing a Learner-Centered Syllabus, which contributes to establishing rapport and improving interaction between a tutor and students, increasing students' motivation and expanding their opportunities. The conclusions, made by the scientists confirm that accompanying a learning activity by a Learner-Centered Syllabus makes students more proactive in the learning process through various interactive events that ensure collaboration, multiple opportunities for formal assessment and ownership of the learning outcomes.

1.2. Selection of an approach to designing a Learner-Centered Syllabus
Designing a syllabus for accountants, [24] chose a holistic approach to learning and assessment of a course in Information Technologies and focused on presenting a system of assessment that facilitates the students' understanding of the academic priorities. Developing and implementing a course in complier design for computer engineering students, [25] promote a pedagogical model known as "learning as a research activity". The researchers improved the course, and the classical pattern of classroom activity was replaced by an active working environment, which resembled that of a group of novice researchers under the supervision of an expert. To engage students into an active research activity, the scientists offered to acquire fundamental concepts through problem-solving, which is closely connected to the construction of scientific knowledge. [26] shared their experience in designing components of a Learner-Centered Syllabus, which has a positive impact on the process of teaching and learning. In order to present the syllabus as a quality product, the scientists recommend to constantly project the "students' voice" on its design and improvement through revisions of the problems that students encounter.

Defining the content of a Learner-Centered Syllabus, the authors of the present article took interest in a study by [27], which shows that expanding the experience and fulfilling the potential has to take place in the environment, which has *Congruence*, that is being genuine, open and transparent; *Acceptance*, which includes respect and unconditioned positive attitude to the learning process; *Empathic understanding*, which means accepting other people's feelings and empathising with them. Undertaking the analysis of the research papers of the aforementioned authors helped the researchers to define the objective of the present study.

The objective of the present study is to design a Learner-Centered Syllabus for a training research workshop in Mathematical Analysis for Master students, majoring in Mathematics at teacher training universities; to evaluate the designed Learner-Centered Syllabus and confirm the efficiency of its introduction in order to engage Master students into the course in Mathematical Analysis.

2. Materials and methods

2.1. The method for designing the Learner-Centered Syllabus

With the help of The Deductive Content Analysis of the resources (Faculty Focus [28], The Chronicle of Higher Education [29], Cult of Pedagogy [30]), that contain guidelines on developing syllabi, the authors of the present research identified the rubrics and the structure of the Learner-Centered Syllabus of the training research workshop in Mathematical Analysis for Master students, majoring in Mathematics at teacher training universities.

Also [31] method, designed to evaluate a learner-centred syllabus, was taken into account. According to this method, the main requirement for the syllabus under development is the presence of three key components: willingness to create a community, allocation of power and control in the community, clearly defined links between the learning performance and its assessment. Detailed description of the method will be presented later in the text of the section.

At the next stage, the content of the Content-Focused Syllabus was analysed and the rubrics of the syllabus were reviewed. The authors of this paper discussed the students' performance results, the description of the tasks and projects, as well as the description of the actions and strategies, used by the teachers to facilitate the learning process and to promote the atmosphere of acceptance, support, respect and positive attitudes.

The general course information. In order to replicate the atmosphere of acceptance and congruence, the information was presented as an invitation.

> Dear attendees of the training research workshop in Mathematical Analysis,
> We are happy to share a new learning experience with you and believe that research potential is inherent in every person. Our course will last for seven weeks during the second term. The meetings will take place twice a week, every Wednesday and Friday 9.45 till 11.00 a.m. in a research laboratory of Mathematics and Learning Methods Department (Room. 6211) or in the lecture hall (Room 6209), 72, Academichna Str., Building 6.
> We believe that we will be able to facilitate your learning, since our tutors are young, tolerant, creative and open. You can approach:
> Oleksii Skachko, DSc, Prof. – the course lecturer;
> Time and place of consultations: Room. 6210, 8.30 a.m. till 3.30 p.m.;
> tel., viber +380509906754, 8.30 a.m. till 6.30 p.m.;
> e-mail: ivin@gmail.com – any time;
> Facebook Messenger – any time;
> skype ivin.79.m 8.30 a.m. till 6.30 p.m.
> Mariia Ivanova, PhD, Assoc. Prof. – Assistant Lecturer;
> Time and place of consultations: Room. 6210, 8.00 a.m. till 3.00 p.m.;
> tel., viber +380736549801, 9.00 a.m. till 6.30 p.m.;
> e-mail: fgmariya@gmail.com – any time.

The course description. Being aware, that a research activity of scientists is closely connected to their interaction with the social environment, in this section the focus is placed on developing personal qualities, necessary for team work. As the research process has a dynamic nature, it must be related to the necessity to solve the problems and deal with the situations constructively. Here is the description of the key components of this section, presented as follows:

The course purpose. Science develops, if people develop! The main purpose of our course is to contribute to better understanding of the nature of the research process by every student. We are willing to teach you how to manage your creative mathematical thinking, to convey own ideas and innovations to the scientific community.
The course objectives. Any scientific activity is done by people, with their subjective personal qualities and way of thinking that is why the objective of our course is to develop the following skills:
- establishing interpersonal connections, working with like-minded people and opponents;
- responsible attitude to own learning and joint responsibility for team work;
- solving research problems and dealing with the scientific situations constructively;
- mathematical, logical and creative thinking, that can provide a feasible algorithm for obtaining scientific knowledge in Mathematics;
- productive thinking, urged by non-conventional and novel nature of scientific knowledge;
- doing independent analysis of the factual material, its critical comprehension.

The course outcomes. As a result of taking the course, you will be able:
- to collaborate with tutors and group-mates in student and scientific communities, to maintain a dialogue and a scientific discussion; to take the lead and group responsibility;
- to plan and manage own efforts in the research process;
- to obtain new knowledge, to do critical analysis, synthesis and evaluation of the new concepts; to search, process and analyse information from various sources;
- to understand such research methods as analysis, synthesis, analysis through synthesis, classifying, generalizing, systematizing information, etc.

We believe that every student can be successful in the course, so we consider these objectives and outcomes to be feasible. At the same time we will be happy to hear about your expectations in order to define the factual plan and the content of the course. Looking forward to getting your proposals: 72, Academichna Str., Building 6, Room 6210, 8.00 a.m. till 3.00 p.m. daily.

The course plan. In this section you can find a list of past proposals, concerning topics for research projects, a preliminary course structure and learning modes. Students can define what is interesting and meaningful for them. The key element of this approach is not only to give the attendees an opportunity to choose, but also to give them responsibility for their own choice. [27] state, that students must have a choice – to get prepared for the course in advance, or to join it with a clear head, which opens up new learning opportunities. To get prepared for the course, this section of the syllabus recommends scientific papers by [32–34], which present the summarized concepts of the approximation theory of periodic functions.

In this section the attendees learn about an opportunity to choose a computer lab in the cloud. We recommend (but not limit the choice) the system CoCalc (https://cocalc.com) and encourage the students to present the results of calculations in a natural mathematical language, using the systems LaTex (https://cocalc.com/doc/latex-editor.html). Students can create own accounts in CoCalc. Since this environment supports web technology of cloud computing (SaaS), it is necessary to install any browser on your computer. For a convenient group work, a subscription is recommended ($ 14+ per month). It can provide more resources for storage and calculations, increase quotas for one project, which is used by several accounts.

Course plan. We want to give your understanding about the prospective content and scope of the course. Our course is related to the approximation theory of functions of a real variable of trigonometric polynomials, which are built on the basis of the repeated summation of the partial sums of the Fourier series. The choice of this section is determined by its wide usage in practice. We believe that it is necessary to learn about three works, dedicated to different directions of the approximation theory by repeated arithmetic mean of Fourier sums:
1. Qian, T. (2006). Analytic Signals and Harmonic Measures, Journal of Mathematical Analysis and Applications, 314(2), 526-536. This research is dedicated to the problems of time-frequency analysis and is of significant interest for studying the specifics of the analytical signals that induce instant amplitude and frequency.
2. Rovenska, O. (2017). Approximation of analytic functions by repeated de la Vallee Poussin sums. Computer Research and Modeling, 11(3), 367–377. The research concerns the issue of approximation of analytical functions by repeated Fourier sums. It also states the conditions, under which the received formulas are asymptotically precise.
3. Novikov, O. and Rovenska, O. (2017). Approximation of periodic analytic functions by Fourier sums. Matematchni Studii, 47(2), 196–201. The work considers asymptotic behavior of precise upper bounds of variations in uniform metric of linear means of Fourier series on classes of analytic periodic functions.

You can get prepared for the course, reading the above mentioned papers or join it, being open to new experience.
During the introductory class we will jointly decide:
- what to study – which direction is the most interesting (a few options can be chosen), how to work on the topics;
- how to study – how to arrange the process of giving lectures, discussions, seminars, types of group and individual work, communication out of classroom (watching films, presentations, etc.);
- what virtual online computer lab will be used in the course;
- how to evaluate – the assessment methods will be chosen (for instance, an exam, a presentation of a group research, oral reports) as well as the approaches to grading (self-assessment, peer assessment, assessment by a tutor, expert opinion, etc.).

Your expectations and proposals are welcome!
The actual course plan will be defined at the introductory class after careful discussion and consideration.

The learning environment. In this section it is important to show not only encouragement, but also a requirement to collaborate throughout the course. A research by [35] states, that if students develop the strategy for the group behavior on their own, they experience negative attitude to the course less frequently. Implementing the component of Empathic understanding takes place through accessibility of the course resources to all the attendees. The recommended resources, such as [36–40] are in open access.

Class participation. Every now and again, all of us need assistance. If you fail to understand the lecture material or are unable to work out the individual task, please approach us or any other member of the group. We would also be grateful if you share the links to the sources of useful information with other group members. We expect you to take responsibility, sharing your knowledge with your peers through discussions or presentations. Since active participation is the best way to acquire knowledge, we encourage you to be proactive in the course!
Resources. There are two basic manuals you may need to work with:
1. Trefethen, L. N. (2012). Approximation Theory and Approximation Practice. Society for Industrial and Applied Mathematics, University City Science Center Philadelphia, PA, USA.
2. DeVore, R. A. and Lorentz, G.G. (1993). Constructive Approximation, Springer Verlag Berlin Heidelberg.
Additional Reading:
1. Miller, S. S. and Mocanu, P. T. (2000). Differential Subordinations: Theory and Applications, Pure and Applied Mathematics, No. 225, Marcel Dekker, New York.
2. Rovenskaya, O. G. and Novikov, O. A. (2020). On approximation of classes of analytic periodic functions by Fejer means. Chebyshevskii Sbornik, 21 (4), 218–226.
3. Keogh, F. R. and Merkes, E. P. (1969). A coefficient inequality for certain classes of analytic functions. Proceedings of the American Mathematical Society, 20, 8–12.
The books are in open access on Google Books (books.google.com), or you can order them from the library in 72, Academichna Str., Building 1, Room 1217.
In addition to the manuals we will use interesting materials from educational online platforms Khan Academy, Coursera, Prometheus, YouTube; listen to scientists-mathematicians, watch films about famous mathematicians. And much more!
Rules and attendance. After designing the course plan jointly, we need to define the rules. We usually ask students to come up with their proposals concerning behavior and then we vote for those rules. We can discuss:
- how to deal with situations when students are late for classes;
- whether it is necessary to get prepared for classes in advance;
- what activities to do in order to compensate for the missed classes;
- whether it is allowed to use mobile gadgets;
- food and drinks in the classroom.

You must attend every class, but if there is a plausible reason to skip it, please inform us about it. According to the policy of our University, if you have to skip a class, you have an opportunity to join the course remotely, on Moodle platform (http://moodle.dgma.donetsk.ua/enrol/index.php?id=708) in a synchronous or an asynchronous mode.

Assessment. [31, 41] describe student-centred evaluation, when the focus is shifted from the policy of penalties and losing points, to providing options for scoring the points. Grades are related to the learning performance, not the whole scope of work, planned for the course is assessed. A system of combined assessment allows to allocate responsibility to both tutors and students.

We are in favour of a system of combined assessment (table 1), when the roles of a teacher, a student, a group are allocated evenly and are equally meaningful. Thus, the assessment process consists of:
- self-assessment;
- group assessment of a team research;
- assessment by a teacher.

Table 1. A list of assessment methods.

Assessment methods	Types of tasks for assessment	Grades
1. Study and analysis of literature	Discussions, peer questioning, answers during lectures	20
2a. Group research (discussion, proposals, obtaining results, presentations, conclusions and discussion)	Reports, discussions, quizzes, analytical papers, calculations, written descriptions	45
2b. Personal research project	Essays, interviews, analytical papers and calculations	45
3. Final exam	An essay, combined tests, oral answers	35
Evaluation	Total of 1, 2a/2b, 3	100

Revision/retaking. We know, that one of the mechanisms of developing mathematical knowledge is a researcher's desire to improve the scientific results. So, we encourage students' attempts to improve the results of their oral answers and written papers. After the discussion, we will agree upon the number of attempts and deadlines for submitting papers.

The course policies. Inquisitiveness and involvement into the research activity come top on the list of personal psychological attributes of a scientist. The focus of the course is shifted from the intellectual potential to the sphere of personal and psychological qualities in the sphere of motivation. The section shows the key concept behind the course policy, which is aimed at self-development, but not at assessment.

Creating a friendly environment is a key feature of this course. We are willing to see you develop as a researcher. Our policy is:
1. Supporting each and every course attendee at all the stages of the learning process; decision-making and increasing own responsibility, self-respect.
2. Atmosphere of trust, where inquisitiveness and natural desire to learn is developing.
3. Assistance in achieving meaningful internal results.
Empathy and studying own emotions develop the human abilities, necessary for solving problems in new situations successfully.

The course analysis. One of the elements of the system of internal quality assurance, set forth in the Standards and Recommendations on Quality Assurance in the he Standards and Guidelines for Quality Assurance in the European Higher Education Area [42] is learning expectations, needs and the degree of students' satisfaction by the syllabus, educational resources in place and support from a tutor. Person-centred learning complies with the highest degree of trust between a tutor and a student community, so monitoring and the analysis of expectations and emotional atmosphere must be done at all times. The authors of the present study recommend to give students an opportunity to provide feedback at any time during the course. Surveys in Google Forms, talks, joint out-of-class activities can become an efficient mechanism for providing such feedback.

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We are eager to make the course transparent and hope for your trust. We are changing the learning methods to make this course accessible to anybody. Please, send us your proposals and your feedback about the course to: http://moodle.dgma.donetsk.ua/enrol/index.php?id=708

2.2. The methods for evaluating the Syllabus

The syllabi were evaluated, using the method of [31], designed to evaluate a learner-centred syllabus (Rubric for Determining Degree of Learning-Centredness in Course Syllabus). In this article, the authors propose a means of assessing the degree of student-centeredness in modern teaching methods. The rubric developed for this purpose allows the development of a measure of the degree of student-centeredness present in current teaching practice, and used the results as a tool for professional development planning. It allows to cover the whole spectrum of the attributes, typical for the best student-centred teaching practices. The researchers consider, that a Syllabus, designed in compliance with the Learning-Centred approach, is to showcase three key components: willingness to create a community, allocation of power and control in the community, clearly defined links between the learning performance and its assessment. With this in mind, the evaluation is done, following three sets of criteria: *Community*; *Power and Control*; *Assessment and Evaluation*, which encompass twelve subcategories. A four-point scale from 1 to 4 points, that accords with the increase in the level of student-centredness is applied to assess the Syllabus indicators in each subcategory.

3. Results

3.1. The basis of a study

The training research course in Mathematical Analysis is a part of a series of elective courses and is taught to Master students, majoring in Mathematics in the 1st year of study at Kryvyi Rih State Pedagogical University, Kryvyi Rih, Ukraine; Bohdan Khmelnytsky National University of Cherkasy, Cherkasy, Ukraine; Sumy State Pedagogical University named after A. S. Makarenko, Sumy, Ukraine; Berdyansk State Pedagogical University, Berdyansk, Ukraine; Donbas State Engineering Academy, Kramatorsk, Ukraine.

The research was done during 2015/2016–2019/2020 academic years. In 2015 the Learner-Centered Syllabus was designed and improved. At the end of 2015 that Learner-Centered Syllabus was uploaded to the official web-pages of the Mathematics Departments at the aforementioned universities. The academic staff and Master students were engaged into the discussion, which lasted for 2 months. As a result of the discussion, one more section – the Course Analysis was added to the Syllabus. This section provides an opportunity to give anonymous feedback with the help of a survey in Google Forms.

Starting with 2016, every year in each of the mentioned universities all the Master students were divided into two groups. The 1st group was given a conventional Content-Focused Syllabus of the training research workshop in Mathematical Analysis, the 2nd group was given the Learner-Centered Syllabus, designed in accordance with the Person Centered Approach to Teaching and Learning. 416 students took part in the research (23% male and 77% female students, aged 19 to 32). Out of the total number of the attendees, 29% had at least 3 years of working experience and 14% of the attendees obtained a Master degree in other spheres.

3.2. Evaluating the Content-Focused and the Learner-Centered Syllabi

Evaluating a conventional Content-Focused Syllabus and the Learner-Centered Syllabus by the rubric of [31] was done at the beginning of 2016 by a team of independent experts of the platform “Higher School Mathematics Teacher” [43], who have a DSc degree in education and psychology. The expert communication took place on the platform forum. The results of the evaluation of the Content-Focused Syllabus and the Learner-Centered Syllabus is presented in tables 2–4 in grey and yellow respectively.

Table 2. Indicators of the Content-Focused Syllabus (in grey) and the Learner-Centered Syllabus, designed in compliance with the Person Centered Approach to Teaching and Learning (in yellow) – Community.

1	2	3	4	5
Accessibility of a tutor	Accessible only at certain time, out of touch, does not communicate out of class	Accessible in working hours in class, provides the working phone number and e-mail	Accessible not only in working hours, provides a personal phone number and e-mail, encourages interaction	Accessible not only in working hours, accessible beyond the working place, provides a working phone number, e-mail, Skype, other contact details; encourages interaction
Justification of learning	Tasks or exercises are given without any justification	Tasks are justified, but not related to the learning outcomes	Tasks are justified and related to the learning outcomes	Tasks, methods, modes of learning, policies are justified and related to the learning outcomes
Collaboration	Collaboration is banned	Collaboration is allowed	Collaboration in groups is encouraged	Collaboration is urged, sharing experience is encouraged

The average score of the category *Community* for the conventional Content Focused Syllabus, used in the control groups, was 1.67 points; categories *Power and Control* – 2 points; categories*Assessment and Evaluation* – 1.8 points. The total average score of the Content Focused Syllabus is R=1.83.

Below are the rates of the Learner-Centered Syllabus, designed in accordance with the Person-Centered Approach to Teaching and Learning, provided to the students in the experimental groups, when they were selecting a course. The average score of the category *Community* was 3.67 points. Here the evaluation of the subcategory *Justifying the learning* process indicates the necessity to complete the information on the links between the course policy and methods with the learning outcomes. The Syllabus content accords the category *Assessment and Evaluation*, which makes 3.8 points. The category *Power and Control* scored at 3.75 points. When designing materials for the subcategory *Student's Role*, the researchers in the present study tried to take into consideration such component as *Emphatic understanding*, which not always corresponds to the possibility to demand from students responsibility for their choice of the course content. The total average score of the Learner-Centered Syllabus is R=3.75. Growth in the rate of the Learner-Centered Syllabus, against the rates of the Content Focused Syllabus is shown in figure 1.

Table 3. Indicators of the Content-Focused Syllabus (in grey) and the Learner-Centered Syllabus, designed in compliance with the Person Centered Approach to Teaching and Learning (in yellow) – Power and Control.

1	2	3	4	5
Teacher's role	No allocations of power Authoritarian rules are written as directions; the policy of penalties is in place. Differentiated approach is not applied	No allocation of power, a teacher is an authority. Partly differentiated approach to learning, some flexibility in policies is in place	Students' power is limited. The choice of the content, scope and deadlines can be offered.	Joint power of a teacher and students. Students' participation in selecting policies, content, process and methods of learning is encouraged
Student's role	Responsibility for learning is on the student	Responsibility for learning is on the students, some extra work is encouraged	Responsibility for presenting extra material in group	Students are responsible for stating problems, discussion and presentation of extra material
External resources	Manuals are a mandatory; no other external resources are required. A teacher is the primary source of knowledge	Links to external resources are provided, but their usage is not encouraged	Work with external resources is encouraged	Presenting external resources to the community is encouraged
Learning focus	Focus on unconditional following the algorithm. Discussing the algorithm is not allowed	Following the algorithm with its partial justification and explanation	The course objectives are explained. Balance between the policy of the algorithm following and justification	Following the algorithm is minimal. Discussing the learning content, the assessment process

3.3. The description of the process of introducing the Learner-Centered Syllabus

The results of evaluating the Learner-Centered Syllabus, concerning the increase in the degree of student-centredness correlate with the positive growth in the rate of the number of attendees in the experimental groups. In 2016/2017 academic years 12 out of 63 students (19.0%) in the control group chose the research workshop. In the experimental group 17 out of 58 students (29.3%) chose the same workshop. In 2017/2018 academic years the total number of students, doing their 1st year of study in Master program was 87 persons, 43 of whom were from the experimental group. The training research workshop was chosen by 10 students (22.7%) in the control groups and 16 students (37.2%) in the experimental groups. In 2018/2019 academic years, having the same number of students in both groups (47 students), the workshop was chosen by 11 students (23.4%) in the control group and 19 students (40.4%) in the experimental

Table 4. Indicators of the Content-Focused Syllabus (in grey) and the Learner-Centered Syllabus, designed in compliance with the Person Centered Approach to Teaching and Learning (in yellow) – Assessment and Evaluation.

1	2	3	4	5
Grades	Focus on losing points and the policy of fines	Grades are not related to the learning outcomes	Grades are directly related to the learning outcomes. Various ways to score points are in place	Grades are directly related to the learning outcomes. Various ways to score points are in place. Not all the activities are graded
Feedback	Only unit tests and final tests are graded. The grades are announced to students, but they are not allowed to see or keep the test papers	Current activities are partly graded. Testing does not mean communicating with a teacher. Students can see, but not keep the test papers	Grades for current activities are meaningful. Communication with a teacher during testing is in place. Some types of activities are not graded.	The assessment mechanism is based on monitoring the learning process and providing feedback
Evaluation	The final grade is obtained through testing	The final grade is obtained through tests and open-ended tests	The final grade is obtained by current grades, obligatory written papers	The final grade is obtained by current work, written papers, oral reports, presentations, self-assessment and peer assessment
Learning outcomes	The learning outcomes are not defined	The course objectives are stated, but the learning outcomes are not defined	The learning outcomes are visually presented	The learning outcomes are presented and related to grades
Rework and elaboration	Rework and elaboration are not allowed	Rework and elaboration are partly allowed	Rework and elaboration are allowed	Rework and elaboration are encouraged

groups. The total number of Master students in the 1st year of study in 2019/2020 academic years was 114 persons. In the control groups of 50 students, the workshop was chosen by 13 students (26.0%), in the experimental groups of 64 students, it was chosen by 27 persons (42.2%). The comparison of the ratios of the number of attendees of the workshop against the total number of students in 2016/2017-2019/2020 academic years is shown in figure 2.

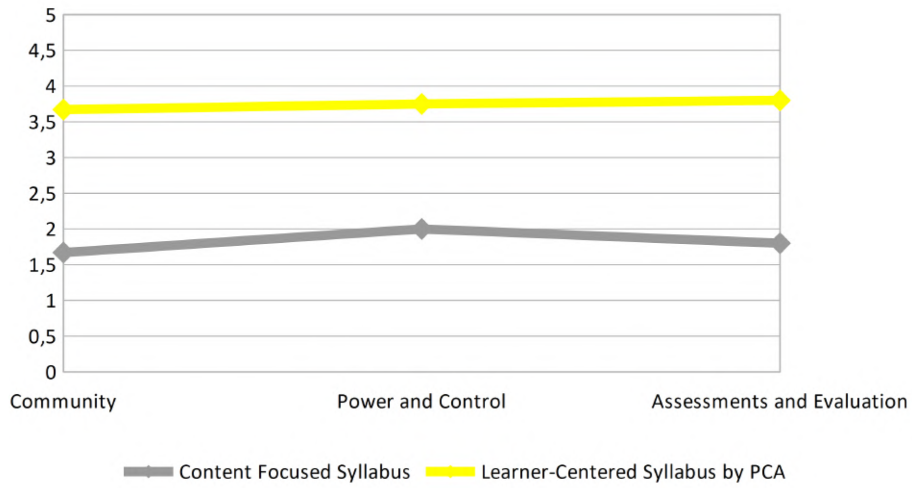

Figure 1. Comparing the rates of the Content Focused Syllabus and the Learner-Centered Syllabus, designed in compliance with the Person-Centered Approach to Teaching and Learning.

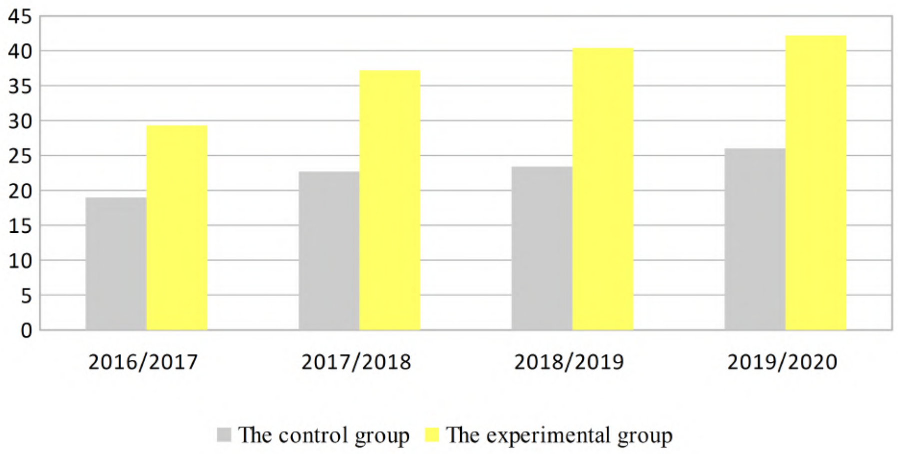

Figure 2. Comparison of the ratios of the number of the course attendees against the total number of students in 2016/2017–2019/2020 academic years.

A high level of rates, concerning student-centredness in the Learner-Centered Syllabus is confirmed by the increasing number of contacts between a tutor and students at the stage of a subject selection. During 2016/2017–2019/2020 academic years in the control groups students did not approach tutors, concerning extra explanation about the content and the nature of the course, that could help them make a choice of a subject. The data, received during a traditional entry survey, conducted before a subject selection are indicative of the fact, that the participants in the control groups, answering the question "Which source of information influenced your choice of the course?" reflects feedbacks from other students as the most important factors (36.4% of the respondents), feedbacks in social media (32.7%) and recommendations from the teachers, whom they know (12.1%). In the experimental groups the students applied for additional counselling when choosing a course from 2 to 9 times per year. The improvement of the collaboration between a tutor and students became a critical factor for increasing motivation in a significant number of attendees to select a course, which is confirmed by the results of the entry survey of the students in the experimental group. When answering the question "Which source of information influenced your choice of the course?", the participants indicated feedbacks from other students as the most important factors (39% of the respondents), feedbacks in social media (18%), counselling of the course tutors (18%), recommendations from the teachers, whom they know (8%) (figure 3).

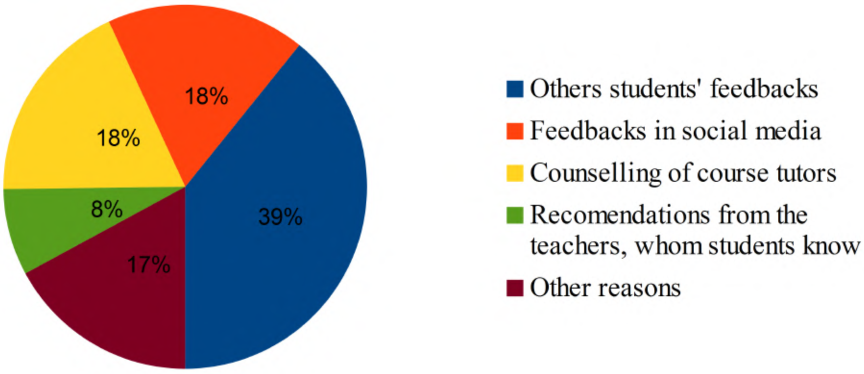

Figure 3. The sources of information that had impact on the students' choice of the course in the experimental groups.

Increasing of the total average score of the Syllabus from R=1.83 (Content Focused Syllabus) to R=3.75 (Learner Centered Syllabus) correlates with the increase in the total number of the course attendees in 2016/2017–2019/2020 academic years from 22.5% to 37.3%. The researchers took into account the fact that in 2017/2018–2019/2020 academic years the feedbacks from the students who had finished the course led to increasing the number of the course attendees, compared to the previous academic year in both, the control and the experimental groups. Due to this, the nature of the correlation between the rates of the Learner Centered Syllabus and the rates of the engagement of students was identified by the nature of the distribution of growth in the number of attendees in experimental groups (Δ_i) by the years of the research (i) (table 5).

Table 5. Distribution of the growth in the number of attendees in experimental groups by the years of the research.

i	2016/2017	2017/2018	2018/2019	2019/2020
Δ_i	10.3%	14.5%	17%	16.2%

The image of the range (figure 4) allows the authors of this study to hypothesise about the even distribution of values Δ_i. Since the distribution of the data presents a small sampling ($n < 15$), using the method of adaptive approximation on the basis of the General Purpose Simulation System (GPSS) $N = 12$ of equiprobably distributed numbers in d–neighborhood ($d = 0.1$) of values Δ_i were generated. The hypothesis about the uniform nature of the distribution on the significance level of $\alpha = 0.05$ was checked with the help of Pearson criterion. The resulting value of $\chi^2 = 8.9$ is not in the critical area $[\chi^2_{cr}; \infty)$, $\chi^2_{cr} = 16.9$, so the hypothesis about the uniform nature of the distribution of the values Δ_i can be accepted. Given that the annual increase in course participants over the last three years of the study was about 14% -17%, and the acceptance of the hypothesis of even distribution, in the future we can expect additional students who use Learner Centered Syllabus at the same level.

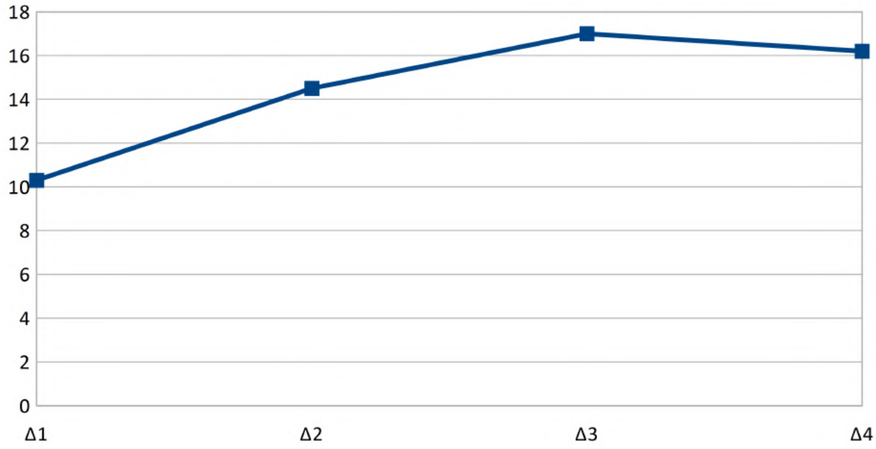

Figure 4. The range of the distribution of values Δ_i.

As the course attendees use information from the Syllabus throughout the term, their further interest in the learning research workshop is linked to the impact of the Learner-Centered Syllabus, designed in accordance with the Personal Centered Approach to Teaching and Learning.

4. Discussion

The issue of engaging students into a research activity has always been of scientific and practical interest for both, researchers and teachers. The most recent studies and work on arranging scientific learning activity of students allowed the authors of the present paper to better understand and comprehend the advantages of introducing a Person Centered Approach to Teaching and Learning. The opinions of [44–47] concerning the importance of applying student-centred methods of learning was taken into account. These methods contribute to developing in students critical scientific thinking, ability to apply analytical strategies.

The study by [19, 48] concerning the methods for developing a research competence in students, confirmed the idea of the authors of the present paper about the necessity to design a Learner-Centered Syllabus. The choice of a syllabus of this type is justified by the factors of the students' engagement into learning [47], as well as by the specifics of a teacher-student relationship when doing research [27]. The syllabus developers forecast engaging students into developing the course content throughout the development process. As [49] state, such an approach to applying the Learner-Centered Syllabus is more positive, as students are more engaged into the process of the course development and perceive their tutors as more creative, caring, responsive, reliable and interested.

Developers of the present syllabus analysed a study by [19, 21, 50] in order to find the sequence of the units and develop content for the training research workshop in Mathematical Analysis within the framework of the Learner-Centered Syllabus. According to [41, 51], careful development of the structure and sequence of components in the Learner-Centered Syllabus facilitates the transition to student-centred teaching. The authors of the present paper make the structure of the Syllabus more detailed, so that it means performing defined roles by students and a tutor, having the learning outcomes, assessment standards and procedures. Following the recommendations from scientists, the authors also gave personalised content to each section of the syllabus. The General Course Information was presented as an invitation. The Course Description was given content, factoring in the dynamic nature of the research process and focus on team work. The content of the Course Plan was discussed by the students. The main idea behind the Learning Environment was to showcase collaboration in the course. The Assessments section states a combined process of assessing the students' achievements (assessment by a tutor, peer assessment, self-assessment). The Course Policies promote the idea of self-development. The Course Analysis presents the conditions for getting feedback so as to constantly monitor the emotional atmosphere in the course. According to the feedbacks from the students, the most meaningful sections of the syllabus are the ones which promote collaboration between tutors and students. These sections encourage students to select the course.

Within the present study one more important aspect was considered – the syllabus evaluation. According to [52], such evaluation is aimed at studying the nature and content of a syllabus in order to understand better its features and attributes; to define ways in which a syllabus reflects and conveys the goals and objectives of a university. A methodology, developed by [31] was chosen by the developers of the Learner-Centered Syllabus to evaluate the training research workshop in Mathematical Analysis. The average score of the Learner-Centered Syllabus by *Community*, *Power and Control*, *Assessment and Evaluation* criteria exceeds the average score of a conventional Content Focused Syllabus by 1.92. Designing the Learner-Centered Syllabus of the course and spreading positive feedback about the course among the students led to their engagement into a research activity in Mathematical Analysis.

5. Conclusions

The studies into creating syllabi and their impact on the students' motivation added to growing interest in a Learner-Centered Syllabus. The reducing number of Master students, majoring in Mathematics, who choose research courses, made the authors of this paper study the issue of engaging students into a research activity through designing a Learner-Centered Syllabus.

The authors of this article present the Learner-Centered Syllabus of the training research workshop in Mathematical Analysis, which is an elective course for Master students, future Mathematics teachers. The structure, the contents and the mode of presenting the Learner-Centered Syllabus was designed in accordance with the Person-Centered Approach to Teaching and Learning. The aforementioned factors led to creating the learning environment, which is defined by the emotional components of *Congruence*, *Acceptance* and *Empathic understanding*. This syllabus has a positive impact on the degree of engagement of the students into the training research workshop in Mathematical Analysis, which allowed the authors thereof to prepare guidelines for developing Learner-Centered Syllabi of research courses:

– combining friendly tone of the Syllabus and mathematical brevity in presenting the guidelines of the course, determines the first positive impression from it and contributes to spreading this impression among other students;

– giving personalised content to each section of the syllabus together with delegating certain authority to students is an important step to an informed choice of the discipline;

– focus on team work creates conditions for collaboration in the course, reducing negative attitude to it;

– discussing the ways to unite the scientific community leads to developing personal qualities of the future scientists, who are ready to make a contribution into creating their own social environment;

– giving students an opportunity to make a choice when doing research projects with practical content, leads to developing responsibility for their own choice;

– being aimed at self-development of students, the course mobilizes them during the decision-making and makes them more confident;

– introducing the policy of achievement points, giving various options for scoring them in the course without any penalties contributes to breaking the barriers between students and tutors, the latter being perceived as friendly and caring.

The authors of the present study see the prospects for further research in introducing the practice of using Learner-Centered syllabi, designed in accordance with Person-Centered Approach to Teaching and Learning in other mathematical courses of a research nature.

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A model of learning the online course “Creative Thinking through Learning Elementary Maths”

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A model of learning the online course "Creative Thinking through Learning Elementary Maths"

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Abstract. The article considers the development of the online educational model "Creative Thinking through Learning Elementary Maths" and the results of the efficiency to implement this course for students of the specialization "Mathematics" while learning Elementary Mathematics. The research represents the development of learning materials for the online course posted in free access on the educational platform "Higher School Mathematics Teacher". The course components (theoretical, practical, and feedback) are focused on the organization of motivated and consistent students' activity; open and integrative Rich tasks of three levels of complexity. The course participants' activity, focused on the recognition, classification, solution, creation of Rich tasks, encourages the formation of the main components of creative thinking that include a problem statement, fluency, flexibility, originality, and elaboration. The first version of the course materials was improved following course users' wishes, and then the efficiency of online course education was checked using an experiment. The analysis of results of the experiment allows concluding about the efficiency of the developed model of learning an online course.

1. Introduction

1.1. Problem statement

According to the World Class Standards for Preparing Teachers of Mathematics [1] the development of creative thinking is one of the necessary components of the Mathematics teacher's training. The same document also mentions that the development of all key qualities of a would-be teacher takes place while teaching normative and optional subjects. Elementary Mathematics is one of the most important normative subjects while training students of the specialization "Mathematics". According to Vlasenko et al. [2], students' revision, generalization, and extension of knowledge in mathematical terms and facts that were considered during the school course of mathematics take place while learning this subject.

Our research follows the idea given by Noreen and Rana [3], Ahn and Edwin [4] that the formation and development of key personal qualities (including creative thinking) while learning Mathematics should be based on the active approach to learning. Scientists' conclusions prove that it is motivated and organized students' activity while learning that allows forming the necessary qualities. The types of activity and problems that students follow while learning depends on the qualities that the teacher is planning to form.

Nowadays, education is aimed at searching the ways to enable the organization of students' extracurricular activities. Thus, learning through online courses is getting more popular in the modern conditions of education development, and the idea given by Vlasenko et al. [2] about the development of the online course "Creative Thinking through Learning Elementary Maths" [5], which is focused on the development of creative thinking with systematized types of problems, is appropriate. This fact proves the actuality of the matter to create a model of learning this online course.

1.2. Analysis of the latest researches and publications

The matters of implementing online courses in learning Mathematics are considered in the researchers conducted by Vlasenko et al. [6], Wajeeh D. et al. [7], Ahn and Edwin [4] etc. In particular, the work which was done by Vlasenko et al. [6] represents the methodology of developing learning materials for the online course "Project method in teaching higher mathematics" [5]. The research by Ahn and Edwin [4] is dedicated to the use of efficient methods for learning mathematics online based on the active approach on the open platform of electronic education. Wajeeh et al. [7] describe the factors that affect the effectiveness of online courses for would-be math teachers. Scientists explain the importance of considering personal qualities and the selection of types of activity for students while learning. The above-mentioned scientists agree that online learning of mathematics has powerful potential and can be organized following the active approach to education, clear explanation of theoretical facts.

The process of building a model of learning the online course is considered in the works written by Ahn and Edwin [4]. Ahn and Edwin [4] mention a model of learning mathematics, based on the principles of social constructivism, social realism, connectivism, and it includes the organization of students' interactive activity to solve mathematical problems. Raza and Reddy [8] emphasize the importance of organizing problem activities and organizing effective feedback in synchronous and asynchronous mode as a condition for activation and interest of students in the process of mastering the online course. Our research considers the scientists' ideas on the relevance of organizing free communication in two directions "student-teacher" and "student-student". Puzziferro and Shelton [9] emphasize that, first of all, the efficient model of the online course, includes the completion of practical tasks using the methods of active learning and organization of feedback between the teacher and course participants. All the scientists agree about the necessity to build a model considering the active approach and efficient organization of feedback.

The active approach during the organization of the online course is considered in the researchers conducted by Moreno-Guerrero et al. [10], Hjalmarson [11] and Poultsakis et al. [12]. Moreno-Guerrero et al. [10] dedicated their research to the efficiency of electronic education as a method to form motivation, skills for self-education, and self-development while learning mathematics. The scientists mention that the organization of online and offline activities with properly selected problems encourages the formation of such qualities as self-organization and self-development. Poultsakis et al. [12] show teachers the importance of mastering digital object management technologies and modeling virtual experiments for online-based online learning.

The results of the research conducted by Hjalmarson [11] prove that all the key personal qualities of a mathematics teacher are developed during this activity (specifically organized practical – focused activity) while learning online. The development of the idea to organize practical-focused activity is stated in the works done by Kajander at el. [13], who emphasize the importance of specifically selected problems in this process.

We find the same point of view in the researchers conducted by Gojak [14], Yeo [15], who states that the development of students' creativity can take place while solving particular types of problems. Among the methods that encourage the development of students' creative thinking, the scientists highlight Rich tasks. This idea is agreed with the conclusions of the research conducted by Vlasenko et al. [2]. The scientists consider Rich tasks in Elementary Mathematics as the tasks that increase the interest in mathematics as a science because they enable students "to open" new mathematical rules (terms, patterns), act outside the box; develop creative thinking, interest in the creation of their mathematical product. In this document, scientists define five main components of developing participants' creative thinking (a problem statement, fluency, originality or creativity, elaboration).

The scientists recommend the development of the online course "Creative Thinking through Learning Elementary Maths" for the efficient formation of the mentioned components of creative thinking [2]. The idea of creating this course was approved during the conference "Icon-MaSTed" [16]. So, the article is aimed at representing an educational model of the online course "Creative Thinking through Learning Elementary Maths" [5] and at proving the efficiency of implementing this course while training students of the specialization "Mathematics".

2. Method

The active approach to learning is the basis of the developed course "Creative Thinking through Learning Elementary Maths" [5]. The foundation for the formation of five main components of creative thinking was the students' work with two types of Rich tasks (open and integrative). Based on the analysis of the views of scientists presented in table 1 on the learning of Elementary Mathematics to the main types of participants' activities while working with the course materials are their recognition, classification, solution, and creation.

In particular, the activity to recognize Rich tasks encourages the formation of such a component of creative thinking as a problem statement. The participants get a task (to determine if a particular problem is related to Rich tasks or some specific types of Rich tasks), formulate the problem, get acquainted with the criteria of Rich tasks, find out if the task satisfies these criteria, and make a conclusion. Thus, the solution to the problem encourages the formation of such components as fluency, flexibility, originality, elaboration.

Considering the opinion given by Vlasenko et al. [16], Ahn and Edwin [4], Moreno-Guerrero et al. [10], Wajeeh et al. [7], Gojak [14], Kajander at el. [13] we built a model of the online course "Creative Thinking through Learning Elementary Maths" [5] represented in figure 1. The scientific novelty of the model is that all the traditional components of the course (theoretical, practical and feedback component) are focused on the organization of four activities with a special type of task (Rich task). It is the activity orientation of the online course on the use of Rich tack that is the basis around which the course model was developed. The model includes three interconnected components of the course (theoretical, practical, and forum for feedback) and implies a motivated students' activity with Rich task.

The course is meant for students of the specializations "Mathematics" and "Natural sciences" of pedagogical and classical universities, postgraduate students who are interested in the efficient methods of forming creative thinking through solving problems of Elementary Mathematics.

Six lessons of the course are given in Ukrainian. The course lasts four weeks. The user can start learning at any convenient time and follow their pace. We assessed the maximum time for working with every class and it is 4 hours. The total time of working with the course is 24 hours.

Let's describe the blocks of the course.

The 1st block. The theoretical component of the course. This block includes the main

Table 1. Analysis of the views of the scientists and online resources on the types of activities with Rich tacks and their impact on the development of students' personalities.

Resource	Rich tacks used during training	Rich tacks activities	What components of personality are developed by working with Rich tacks
Creative Thinking: Innovative Solutions to Complex Challenges [17]	Business management	Creation, solution, comparison	Ability to pose and solve problems, generate a large number of original ideas
Universalclass. Creative Thinking [18]	A course aimed at the general development of creative personality traits	Recognition and comparison	Ability to solve problems, flexibility of thinking, ability to analyze and highlight the basics
European Schoolnet Academy. Developing Creative Thinking Skills in Practice – are my students learning to creatively solve problems [19]	Higher school teachers. A course aimed at the general development of creative personality traits	Recognition and classification	Ability to pose the problem, originality, ability to continuous improvement
School Education Gate Way. Creativity for the future: promoting Critical Thinking and Problem-Solving in the classroom [20]	Teachers and education managers. A course aimed at the general development of creative personality traits	Creation and solution	Ability to pose and solve problems, generate a significant amount of original ideas, flexibility of thinking

theoretical data on every lesson that is necessary for the participants to achieve the goal of the course and audio presentations that explain the main theoretical questions of the course. Let's state the topics of the course.

Lesson № 1. Creative thinking and its structure.

Lesson № 2. The role of Elementary Mathematics in the development of creative thinking.

Lesson № 3. Open tasks in Elementary Mathematics.

Lesson № 4. Types of open tasks in Elementary Mathematics.

Lesson № 5. Integrative tasks in Elementary Mathematics.

Lesson № 6. Types of integrative tasks in Elementary Mathematics.

The acquaintance with the theoretical component of the course encourages the students to do the following types of Rich tasks: recognition, classification, and solution. In particular, in the second lesson, the users get acquainted with several approaches to the classification of Rich tasks, their special features, and types. This encourages the primary organization of the activity to recognize Rich tasks. After learning the theoretical block the course participants improve their recognition skills while doing the practical tasks.

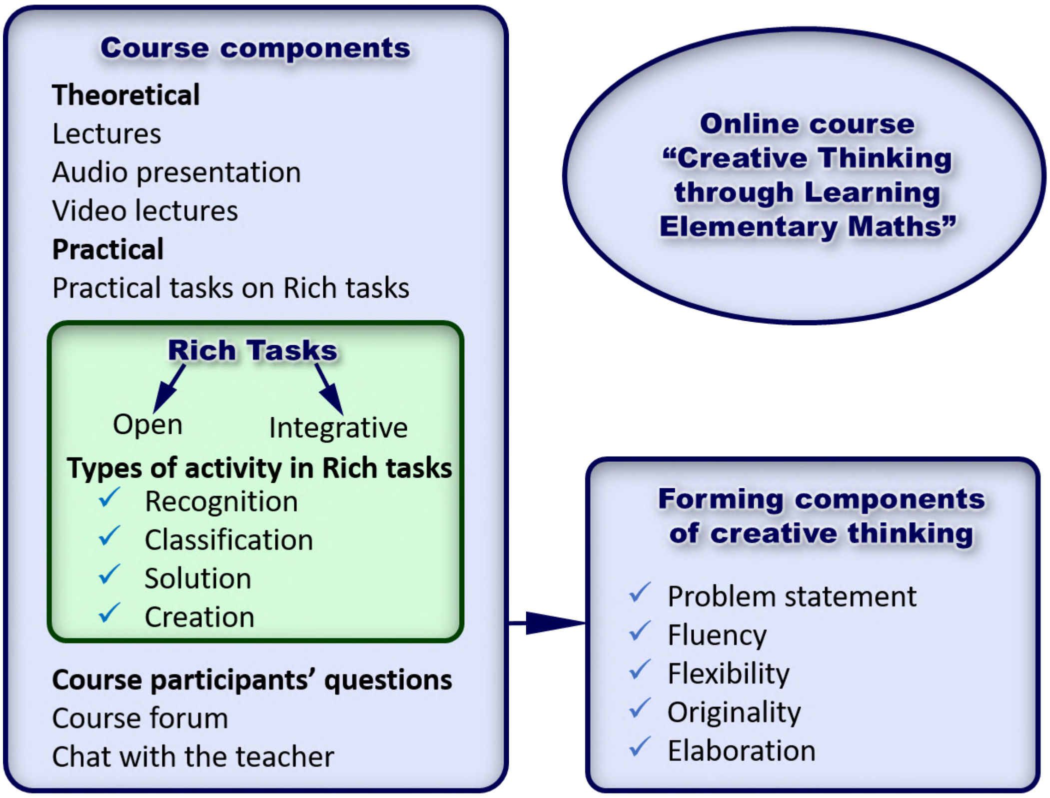

Figure 1. Model of learning online course "Creative Thinking through Learning Elementary Maths".

At the third, fourth, fifth, and sixth lessons, the users get acquainted with open and integrative Rich tasks, their examples, types, and methods of their solution. This encourages the primary organization of the classification and solution of Rich tasks. The course participants master their skills to classify and solve problems while completing practical tasks.

The second block. The practical component of the course. This block includes:

Practical tasks connected with the analysis of different aspects of developing creative thinking, the analysis of methods to learn Elementary Mathematics aimed at the development of creative thinking, comparisons, solutions, building Rich tasks of Elementary Mathematics. Completing practical tasks of the course encourages such types of activity with Rich tasks among students as recognition, classification, solution, and creation.

Several examples of the tasks aimed at carrying out all the mentioned types of activity are represented in table 2.

The third block. Course participants' questions which the course moderators can be asked on the forum and in the chat with a teacher. Participants' ideas on the course improvement can be expressed.

The third block helps to eliminate the problems in organizing the recognition, classification, solution, and construction of Rich tasks that were completed during the first two blocks. Also, the third block helps the teachers to improve the learning material of the first two course blocks.

3. Results

The first version of the course was offered for students of the 1st–2nd year of Berdiansk state pedagogical university, Kryvyi Rih State Pedagogical University, Donbas Machinery Building

Table 2. Examples of practical tasks aimed at completing particular types of activity with Rich tasks.

Type of activity	Examples	Comment
Recognition	1. Can we relate such tasks to Rich tasks? Prove your mind. A. Simplify the expression: $\frac{\sin 80^\circ}{2\cos^2 40^\circ}$. B. The perimeter of the parallelogram is $20cm$, and its height is $2cm$. and $3cm$. Create two tasks of different levels of complexity using these conditions (no more than one condition can be added). 2. Which of the stated problems can be related to open Rich tasks? Prove your mind. A. Solve the equation $\sqrt{2+\sqrt{2+\sqrt{2+x}}}=x$. B. Define the approaches of solving irrational equations and inequalities and an approximate basis of activity on using these approaches while analyzing the educational materials on Elementary Mathematics and school textbooks.	Problem statement as a component of creative thinking is formed while completing this task.
Classification	Which types of Rich tasks are the problems related to? A. the endless chessboard there are two white officers on two neighboring diagonal squares. What part of the board is under the attack of these officers? B. The foundation of an isosceles pyramid is an isosceles triangle which height is $9cm$ and the platform is $6cm$. Create three problems of different levels of complexity using these conditions (no more than one condition can be added). C. Sunbeams going through small holes between the leaves of the tree create light spots on the ground in form of ellipses of the same form, but different size. The bigger axis of the ellipses is $a = 16cm$, and the smaller axis is $b = 12cm$. What is the height of the tree? Under which angle to the horizon do the sunbeams fall? The angle size of the sun disk is $\beta = 9.3 \cdot 10^{-3} rad$.	While solving such a problem the participants determine the problems as open or integrative Rich tasks, later on, they learn to define the varieties of open and integrative Rich tasks. Such activity encourages the formation of such components of creative thinking as a problem statement and flexibility.

Solution	1. Classify the types of problems following the topic "Polygon"; show the main methods (means) of solving the problems using two of the types which you suggest. 2. One student has 6 books on Mathematics, the other one – 8. Create and solve two problems of different levels of complexity on combinatorics, under this condition. 3. Prove that for all $0 < x < y\frac{\pi}{2}$ there is an inequality $\frac{y}{x} < \frac{\tan y}{\tan x}$. 4. The bus is moving on a straight highway with a speed of $18m/s$. There is a person in the field in front of the bus, in the distance of $90m$ from the highway and $500m$ from the bus and who can run with the speed of $5m/s$. What direction should he/she run to be able to "catch" the bus?	While solving these problems the participants learn to summarize, use the mathematical machine beyond mathematics, understand the connection between Elementary Mathematics and mathematical analysis (while solving the third problem). The next components of creative thinking are formed: fluency, flexibility, and originality.
Creation	1. Create three problems (problematic situations) in Elementary Mathematics. 2. Create one task for each problem with an open ending with equations, polygons, random events in the condition. 3. Create one task for each problem the solution of which will enhance the understanding of connections between Elementary Mathematics and Mathematical Analysis, Geometry, Mathematical Logic.	While building the varieties of open and integrative Rich tasks the participants form the following components of creative thinking: fluency, flexibility, originality and elaboration.

Academy, Uman State Pedagogical University named after P. Tychyna, Glukhiv National Pedagogical University in 2019 – 2020. The students were surveyed on the forum of the platform "Higher School Mathematics Teacher" [21] about the test improvement. 65% of respondents were willing to get more examples of Rich tasks, 60% of students would like to have clearer guidelines about the systematization and creation of open and integrative problems in Elementary Mathematics, 53% of students were willing to have online consultations while completing tasks of the practical part of the course. We changed the materials of the course according to the needs of its users. Students' ideas influenced the increase of examples in all types of Rich tasks during practical classes 2-6 and definition of the main requirements to the creation of an open and integrative Rick task during practical lessons 3 and 6.

The efficiency to implement the online course was checked in April-November 2020. 87 students of the 1st-2nd year from the same universities who took part in the first stage of implementing the first version of the course were engaged in the experiment. At the beginning of the experiment the participants were accidentally divided into control (CG) and experimental (EG) groups. In the control group, 43 students learned the course of Elementary Mathematics using traditional tasks. In the experimental group, 44 students followed the program "Creative Thinking through Learning Elementary Mathematics".

Table 3. The results of diagnostic tests in Elementary Mathematics at the beginning of the experiment.

The level of student achievement CG				The level of student achievement EG			
1–49 points 1 (2%)	50–75 points 16 (37%)	76–89 points 17 (40%)	90–100 points 9 (21%)	1–49 points 1 (2%)	50–75 points 17 (39%)	76–89 points 16 (36%)	90–100 points 10 (23%)

To confirm the homogeneity of the groups at the beginning of the experiment, diagnostic tests in Elementary Mathematics were used, which contained 5 "traditional" and 5 Rich tasks.

As we see in table 3 the results of diagnostic tests in the control and experimental groups at the beginning of the experiment are almost the same. In particular, the largest difference of 4% was observed between students who scored 76 – 89 points in favor of the control group (figure 2).

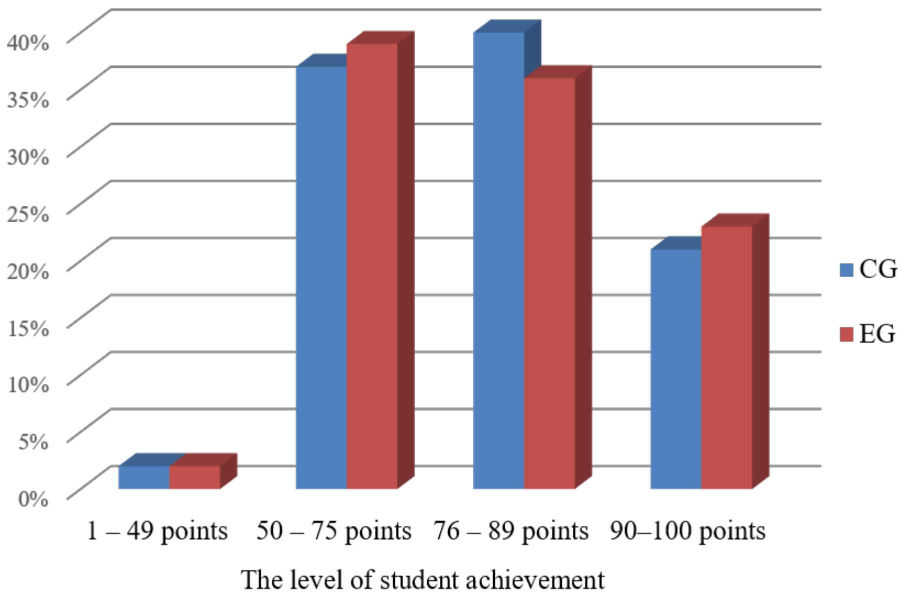

Figure 2. The results of diagnostic tests at the beginning of the experiment.

The students of CG learned the course of Elementary Mathematics in universities without using the course "Creative Thinking through Learning Elementary Maths" [5]. The students of EG learned the course of Elementary Mathematics and during 6 weeks were involved in the development of the course. The students of EG could get acquainted with the theoretical material, watched the audio presentations, worked with video lectures, got practical tasks of the course. Using Google class students could send the completed practical tasks for the teacher to check. The task assessment was carried out using the scale "accepted" or "not accepted". The teacher pointed out the mistakes and incorrectness in the completed tasks, allowed correcting them when the mark was "not accepted". Students could ask a question or get a consultation

Table 4. The results of diagnostic tests in Elementary Mathematics at the end of the experiment.

The level of student achievement CG				The level of student achievement EG			
1–49 points	50–75 points	76–89 points	90–100 points	1–49 points	50–75 points	76–89 points	90–100 points
1 (2%)	15 (35%)	18 (42%)	9 (21%)	0 (0%)	6 (14%)	21 (48%)	17 (38%)

on the forum of "Higher School Mathematics Teacher" [21] or in Google chat.

At the end of the experiment, the students were also surveyed using tests in Elementary Mathematics, which contained the same number of traditional tasks and all kinds of Rich tasks.

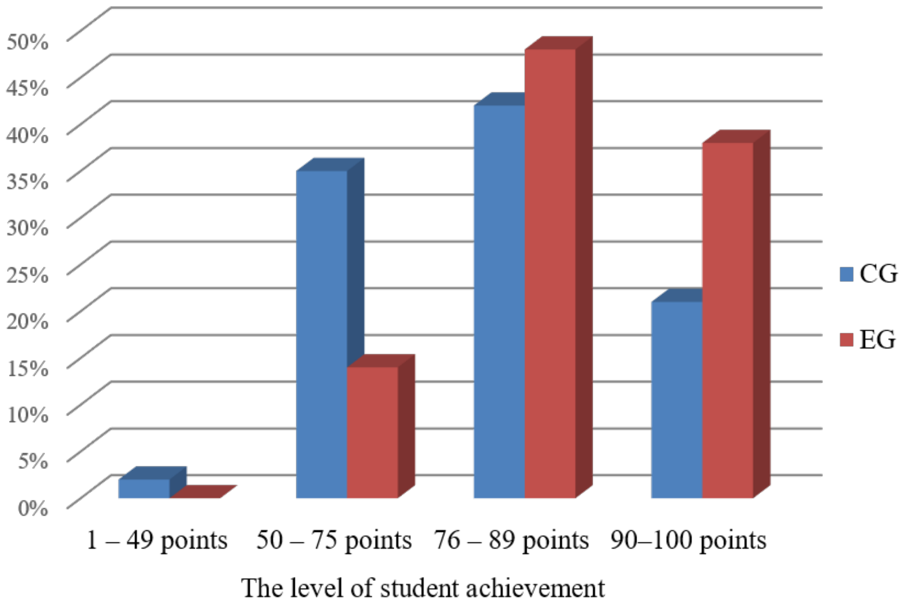

Figure 3. The results of diagnostic tests at the end of the experiment.

As can be seen in table 4, the results of control works in the control and experimental groups at the end of the experiment differ significantly. In particular (figure 3), the largest difference of 18% was observed between students who scored 50 – 75 points in favor of the control group, while the difference of 16% was observed between students who scored 90-100 points in favor of the experimental group. Fisher's statistical test φ^* was used to ensure that the difference between the results of the diagnostic tests in the control and experimental groups was statistically significant.

We formulate statistical hypotheses. Zero hypothesis H_0: the level of formation of educational achievements of students of control and experimental groups does not differ statistically significantly. Then the alternative hypothesis H_1: the level of formation of educational achievements of students of control and experimental groups is statistically significantly different.

Determine: $\varphi_1(86\%) = 2.373$, $\varphi_1(63\%) = 1.831$.

Table 5. Table for calculating the criterion φ^* for comparing the level of student achievement at the end of the experiment.

Group	"There is an effect", scored points from 7 to 12	"No effect", scored points from 1 to 6	Total
Control	27 (63%)	16 (37%)	43
Experimental	38 (86%)	6 (14%)	44
Total	65	22	87

Hence we have the empirical φ^*:
$\varphi^*_{empirical} = (\varphi_1 - \varphi_2)\sqrt{\frac{n_1 \cdot n_2}{n_1+n_2}} = (2.373 - 1.831) \cdot \sqrt{\frac{44 \cdot 43}{44+43}} \approx 2.53.$

The critical value φ^* for any n_1 and n_2 is equal to $\varphi^*_{critical} = \begin{cases} 1.64 & (p \leq 0.05) \\ 2.31 & (p \leq 0.01) \end{cases}.$

So, according to $\varphi^*_{empirical} \approx 2.53$ we have that $\varphi^*_{empirical} > \varphi^*_{critical}$.

Based on this, the hypothesis H_0 is refuted and H_1 accepted. Thus, the level of formation of educational achievements of students of control and experimental groups is statistically significantly different. And the data given in table 5 give grounds to claim that the level of academic achievement of students in the control group is higher than in the experimental group.

This allows stating about the efficiency of using the online course "Creative Thinking through Learning Elementary Maths" [5] as a method to form key components of creative thinking.

4. Discussion

According to Papadakis et al. [22], Perikos et al. [23], Harpen and Sriraman [24], and Maharani [25] the developed creative thinking is important for any specialist who wants to be competitive in the modern globalized world. Specialists in mathematics are not an exception. This is agreed with the conclusions that are made by Moreno-Guerrero et al. [10], who state that learning Mathematics using online courses is efficient to form the person's creative thinking.

While developing the online course model we considered the opinions stated by Burgess et al. [26], Donnelly and Agius [27], Puzziferro and Shelton [9], Lockwood [28] about the relevance of providing learning materials in different forms such as tables, schemes, audio presentations, video-lectures. At the same time, we considered the recommendations stated by Im and Chee [29] about the importance of organizing efficient feedback with students through forums and chats.

Also, while developing a model the researches by Wajeeh et al. [7], Hjalmarson [11] had an important role and they stated that the development of personal qualities should take place during specifically selected types of activity. Based on the views of these scholars, we have focused each component of the traditional triad of online courses (theoretical, practical and feedback) on four types of activity (recognition, classification, solution, creation) with open and integrative Rich tasks, the formation of all components of course participants' creative thinking takes place [2]. Agreeing with Poultsakis et al. on the importance of building digital object management skills in online courses, we believe that it is equally important (and our research confirms this) to build targeted mindfulness skills with Rich tasks. Thus, solving Rich tasks, a student learns to formulate a problem (a problem statement), opens or offers an unusual (unknown) method, method of solution (formation of originality and fluency), clarifies, changes the way of a solution in case of difficulties (formation of flexibility and elaboration). The student learns to think outside the box, change, improve the condition, and adapt it to the students' needs (formation of originality, flexibility, and fluency).

5. Conclusions

The analysis of the online education experts' resources and scientific researches proved the conclusion about the necessity to develop a model of the online course "Creative Thinking through Learning Elementary Maths" [5]. The peculiarity and uniqueness of the course model is that three main components are determined it (theoretical, practical, and feedback) that are aimed at the students' activity with Rich tasks as a method to develop creative thinking while learning Elementary Mathematics. Posting the course on the platform "Higher School Mathematics Teacher" [21] allowed providing access to it for a large group of students. The students had access to theoretical data with examples and explanations in PDF-documents, audio presentations, and video lectures. Practical tasks were focused on the organization of students' activity with Rich tasks of three levels of complexity. The preliminary approbation of the course, discussion on the platform forum allowed improving its content and organization of learning with its help. Also, it allowed considering the course users' preferences related to information perception and posting. The experimental verification of implementing the improved course proved the efficiency of the course use to form its users' creative thinking. The experiment showed that users' acquaintance with Rich tasks and their varieties (open and integrative problems), organization of their activity on recognition, classification, solution, and creation of Rich tasks encouraged the development of a problem statement, elaboration, fluency, flexibility, and originality. This allows us to argue for the effectiveness of the activity-based online course model; expediency of introduction of a new type of tasks in the process of development of creative thinking in the process of distance learning of Elementary Mathematics – Rich tasks.

We see further perspectives in the development of the methodology to develop students' creative thinking while completing Rich tasks, developing and testing the effectiveness of Rich tasks for the formation of key competencies of the personality of high school students.

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Development of logical thinking of high school students through a problem-based approach to teaching mathematics

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Development of logical thinking of high school students through a problem-based approach to teaching mathematics

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Abstract. This article considers the search for new methodological approaches to teaching high school students mathematics that will promote the development of their logical thinking. Based on the analysis conducted by the authors of the study identified an urgent need to develop the logical thinking of students in mathematics lessons through various methods of solving problems. The authors of the article set out to investigate the factors that will ensure the implementation of a problem-based approach to teaching mathematics. These factors include the choice of a certain type of mathematical problem; selection of a method for solving mathematical problems; compiling a system of problems of one type that require the selection of methods for solving them. The authors reveal the introduction of the problem approach as a method of developing students' logical thinking in the article on the example of solving irrational equations with parameters. The authors of the study explain the value of problems with parameters by the fact that the process of solving them contributes to the formation of students' research skills. In the study, the authors focused on the analytical method of solving problems with parameters. Structural analysis of problems allowed the authors to formulate the following didactic requirements for the system of mathematical problems such as compliance with the problems of the course content and the principle of gradual increase in complexity; the rational relationship between the logical and heuristic components of educational activities; the presence of ideological and technical complexity, etc. To confirm the effectiveness of the introduction of the problem-based approach to the educational process, as a method of developing students' logical thinking, an experiment was conducted. The main objectives of the experiment were to identify the level of logical thinking of students; development and implementation in the educational process of a system of problems with parameters in the study of the topic "Irrational equations", which contribute to the development of logical thinking of students; analysis of the results of the experiment. The obtained results and their statistical processing confirmed significant differences in the levels of development of logical thinking in the control and experimental groups, respectively. This proved the effectiveness of a problem-based approach to teaching mathematics and the development of logical thinking of students.

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1. Introduction

The provisions of the theory of developmental learning emphasize the importance of developing students' logical thinking. All adolescents with mediocre abilities have hypothetical-deductive thinking, but they use this ability differently in different aspects of reality. In conditions of total informatization of society, the formation and development of logical thinking of young people acquire certain features. Mastering the components of logical thinking, such as the choice of problem-solving techniques, a combination of techniques, the development of a general style of mental activity should not be a side but the main learning outcome, in particular in mathematics lessons. It is in the process of learning that a high school student gradually masters such mental operations as a comparison, analysis, synthesis, abstraction, generalization, and concretization. The degree of development of these operations is an indicator of the formation of student thinking. Mental operations are closely interconnected and form a holistic set of operations performed by each person in the process of thinking, so the process of learning and education should ensure the development of logical thinking of students.

An important place in this process is occupied by mathematical education, which involves the search for new methodological approaches that will promote the development of logical thinking of students. George Pólya wrote: "Problem-solving is a specific feature of the intellect, and intelligence is a special gift of man, so problem-solving can be considered as one of the most characteristic manifestations of human activity. To master mathematics means to be able to solve problems, not only standard but also those that require originality, ingenuity, independence of thinking" [1]. Since the teaching of mathematics must make a certain contribution to the development of students 'thinking, one such approach is a problem-based approach to the teaching of mathematics to develop students' logical thinking.

2. Analysis of scientific papers

The question of finding ways and approaches to the formation and development of logical thinking of students and the specifics of such development in the teaching of mathematics has always interested scientists. So in a study by Akbayir and Topcul [2] indicates that success in the study of mathematics directly depends on the level of metacognitive skills and logical thinking of the student, ie awareness of their mental operations. Researchers note that an indicator of a high level of metacognition is the correct interpretation of an educational or live problem, the ability to identify appropriate and inappropriate methods of problem-solving, analysis of the solution after the implementation of the chosen strategy. In their work [3] Kooloos et al. conclude that logical thinking is a necessary condition for successful mastery of mathematics. The authors of the study note that logical thinking is based on a sequence of mental actions – the ability to adhere to logical continuity in the expression of judgments and their justification.

According to Swestyani et al. [4], logical thinking depends on the ability to structure information (by analogy with mental maps), apply inference rules, and use accurate language. Tarasenkova and Akulenko [5] consider the possibility of forming logical thinking of high school students within the study of the elective course "Logic". Researchers offer students the following learning topics: statements and logical operations on them, predicates and logical operations on them, the equivalence of statements and predicates, tautologies, quantifiers, formulas of Boolean algebra, formulas for counting predicates.

Instead, Bakhy et al. [6] are convinced that the development of logical thinking is possible directly in mathematics lessons – by various methods of solving problems, such as the method of analogy, the method of analytical-synthetic reasoning, special cases, trial and error, heuristic method, incomplete induction method, method comparison, the method of proof from the opposite. Tisngati and Genarsih [7] argue that the ability to reason based on "if – then" rules is the basis for mathematical skills because, without conditional reasoning, scientific reasoning is based on hypotheses and their proof or refutation is impossible. The need for reflexive considerations arises in situations that go beyond everyday experience when the problem can not be solved only by the process of finding the necessary information in memory. They emphasize that both mathematical and logical thinking are possible due to the conditions of observance of the rules of inference and processing of abstract or symbolic content. Kurniawati et al. [8] study problem-based learning as means to develop the ability to conclude from existing premises, to estimate the probability of occurrence of the event, to perform combinatorial calculations, to use in reasoning comparisons and analogy.

According to Darma et al. [9], problem-based learning should be implemented in mathematics lessons through a problem-based approach. At the same time, the tasks are an incentive to study and a means of developing the ability to solve any educational and life problems. Johansen et al. [10] emphasize the need to study mathematics by solving problems. Therefore, researchers consider a problem-based approach in the context of problem-based learning and suggest the following stages of its implementation: 1) statement of the educational problem (task); 2) independent mastery of theoretical knowledge necessary for solving the problem; 3) solving the problem; 4) discussion and exchange of knowledge; 5) evaluation.

Ellis [11] considers the problem approach as a method of learning and describes the stages of its implementation: 1) the preparatory stage – solving the input problem; 2) solving a system of problems; 3) the stage of repetition and generalization of methods for solving a problem; 4) reflection – self-evaluation and mutual evaluation. Amadi et al. [12] note that Task-Based Teaching Strategy (TBTS) is almost the only way to transform students from “passive observers” to active participants in the educational process, but recognize that the use of this pedagogical technology is time-consuming, which often contradicts the actual number of hours study of mathematics and complex program requirements for the level of knowledge of students. We aim to develop the logical thinking of high school students in teaching mathematics and therefore chose as a methodological tool a problem-based approach. The introduction of a problem-based approach requires compliance with the following factors: 1) the choice of a particular type of mathematical problem; 2) selection of a method for solving mathematical problems; 3) compiling a system of problems of one type that require the selection of methods for solving them. Adherence to these factors in the teaching of mathematics will contribute to the formation of students’ mental operations and the development of their logical thinking as a whole.

To ensure this approach, certain tasks must be systematized. The greatest potential, according to Vlasenko et al. [13] in this direction have tasks that allow you to form both individual mental operations and develop logical thinking as a whole. Rohaeti et al. [14], Rafida and Permana [15] believe that this type of task can also include research-type tasks.

One of the main content lines of the course “Mathematics” in high school is the line of equations. In the course of algebra and the beginnings of analysis, the topic of “Equations” occupies an important place in the formation of individual mental operations of students, as for research-type tasks, in the topic of “Equations” a special place in this regard are problems with parameters. The ability to solve these problems is rightly considered an indicator of the level of mathematical competence of students. So the analysis [16] of conducting of tests EIT-2021 showed that, as expected, caused difficulties for task 34. This is evidenced by the fact that only 0.2% of test participants were able to completely solve the problem, and 90.2% of test participants did not perform it at all. The problem with the parameters that the students faced belongs to the tasks of the highest cognitive level. Its solution requires not only finding a set of solutions of the system of equations depending on the values of the constant parameter a, but also a thorough analysis and, on its basis, the synthesis of results.

We explain the value of problems with parameters by the fact that these problems allow us to systematize and deepen knowledge on a certain topic of the school course of algebra or several topics, to generalize the ability to solve equations, inequalities, and their systems. In addition, solving problems with parameters aims not only to test thorough mathematical knowledge but also the formation of students' research skills. Problems with a parameter are usually solved by the search method because they require an answer for all possible values of the parameter. Of course, without the involvement of mental operations of analysis, synthesis, comparison, concretization and generalization to solve the problem with the parameter is impossible. In this regard, the process of solving problems with the parameter is developmental and creative.

The article aimed to consider a problem-based approach to learning to solve equations with parameters on the example of the topic of 10th grade "Irrational equations" for the development of logical thinking of students.

3. Methods

The problem-based approach to teaching mathematics as a method of developing logical thinking of high school students involves the following stages.

3.1. Choice of a certain type of mathematical problem

We analyzed the current program in mathematics [17] and textbooks for senior profile classes [16], [18], [19], [20], [21], [22], [23] concluding that in the course of algebra and the beginnings of the analysis of the profile level consider the following types of problems with parameters:

- irrational equations and inequalities;
- exponential equations and inequalities;
- logarithmic equations and inequalities;
- trigonometric equations and inequalities.

Let's focus on the first topic in 10th grade "Irrational equations", and consider irrational equations with parameters.

3.2. Selection of a method for solving mathematical problems

The search method is one of the possible ones for solving equations with parameters. The essence of this method is to study all possible cases of relations between mathematical objects defined by the problem, to select those of them that satisfy the condition of the problem, and to substantiate that there can be no other solutions. To solve the problem by the method of search, you should choose a certain search system, which would give confidence that all possible cases are considered.

It is known that there is no general scheme for solving problems with parameters. In general, analytical and graphical methods are used to solve them. In our study, we will consider in more detail the analytical method of solving problems with parameters.

An irrational equation is an equation that contains a variable under the sign of the root. Accordingly, an equation with a variable and a parameter will be called irrational if the variable is contained under the sign of the root. For example, $\sqrt{x-2a}=1$, $\sqrt{x-3}=x-a$, $\sqrt{a-\sqrt{a+x}}=2x$, $\sqrt[3]{2x+1}-\sqrt[3]{x-1}=a$.

As is known, the main methods of analytical solution of irrational equations are as follows: 1) raising both parts of the equations to the same degree; 2) introduction of new variables. At the beginning of solving an irrational equation, it is useful to find the domain of the equation, because it may be that it is not defined on the set of real numbers.

When solving irrational equations, extraneous roots may appear. Therefore it is necessary to remember that at raising of both parts of equality to an odd degree we receive the equivalent equation, and at raising to an even degree – the equation-consequence. If the equation-consequences are used when solving irrational equations, then checking the found roots is mandatory. The test is usually performed by substituting the initial equation. However, sometimes it is not very convenient to perform the check (for example, if the found roots are

Table 1. Equivalent transformations of some irrational equations.

№	Type of equation	Equivalent transition
1	$\sqrt[2n]{f(x)} = \sqrt[2n]{g(x)},\ n \in \mathbb{N}$	$\begin{cases} f(x) = g(x) \\ f(x) \geq 0 \end{cases}$ or $\begin{cases} f(x) = g(x) \\ g(x) \geq 0 \end{cases}$
2	$\sqrt[2n]{f(x)} = g(x),\ n \in \mathbb{N}$	$\begin{cases} f(x) = (g(x))^{2n} \\ g(x) \geq 0 \end{cases}$
3	$\sqrt[2n+1]{f(x)} = g(x),\ n \in \mathbb{N}$	$f(x) = (g(x))^{2n+1}$
4	$\frac{\sqrt[2n]{f(x)}}{g(x)} = 0,\ n \in \mathbb{N}$	$\begin{cases} f(x) = 0 \\ g(x) \neq 0 \end{cases}$
5	$\sqrt[2n]{f(x)} \cdot g(x) = 0,\ n \in \mathbb{N}$	$\left[\begin{array}{l} \begin{cases} f(x) = 0 \\ x \in D(g) \end{cases} \\ \begin{cases} g(x) = 0 \\ f(x) \geq 0 \end{cases} \end{array}\right.$

irrational or cumbersome in appearance), so it is better to use equivalent transformations of equations. Note that for irrational equations with parameters, equivalent transitions also greatly simplify the solution process. Equivalent transitions for certain types of irrational equations are shown in table 1.

We show the application of the analytical method and the search method on the example of solving an irrational equation with the parameter.

The task. Solve the equation $\sqrt{4x - x^2} = a + 1$ with the parameter a.

The solving. The irrational equation is given and it contains one square root on the left and a parameter (number a) on the right. If $a+1 < 0$ that is $a \in (-\infty; -1)$ then the equation has no solutions: $x \in \varnothing$. If $a+1 \geq 0$ then both sides of the equation can be squared: $4x - x^2 = (a+1)^2$. The quadratic equation $x^2 - 4x + (a+1)^2 = 0$ is obtained. Let's solve this equation.

1. $D = 16 - 4(a+1)^2 = 4(-a^2 - 2a + 3)$.

2. Let's consider the case when $D > 0$ that is $4(-a^2 - 2a + 3) > 0$, thus $a^2 + 2a - 3 < 0$, $a \in (-3; 1)$. Let's take into account that $a \geq -1$. Therefore, if $a \in [-1; 1)$ then $x_{1,2} = \frac{4 \pm 2\sqrt{-a^2-2a+3}}{2} = 2 \pm \sqrt{-a^2 - 2a + 3}$.

3. Let's consider the case when $D = 0$ that is $4(-a^2 - 2a + 3) = 0$, thus $a^2 + 2a - 3 = 0$, $\left[\begin{array}{l} a = -3 \\ a = 1 \end{array}\right.$. Let's take into account that $a \geq -1$. Therefore, if $a = 1$ then $x_1 = x_2 = 2$.

4. Let's consider the case when $D < 0$ that is $4(-a^2 - 2a + 3) < 0$, thus $a^2 + 2a - 3 > 0$, $\left[\begin{array}{l} a < -3 \\ a > 1 \end{array}\right.$. Let's take into account that $a \geq -1$. Therefore, if $a \in (1; +\infty)$ then $x \in \varnothing$.

The answer. If $a \in (-\infty; -1) \cup (1; +\infty)$ then $x \in \varnothing$; if $a \in [-1; 1)$ then $x_{1,2} = 2 \pm \sqrt{-a^2 - 2a + 3}$; if $a = 1$ then $x = 2$.

Methodological commentary. The enumeration method was implemented at the stage of considering all possible values of the discriminant of the quadratic equation $x^2 - 4x + (a+1)^2 = 0$ and all possible parameter values (the set that consists of $(-\infty; -1)$, $(1; +\infty)$, $[-1; 1)$ and 1 is the set of real numbers $\mathbb{R}$. The analytical method was used to write the equation $4x - x^2 = (a+1)^2$ that is equivalent to this on the set $a \in [-1; +\infty)$ (to solve the equation $\sqrt{4x - x^2} = a + 1$ you need to take into account its domain and solve the equation $4x - x^2 = (a+1)^2$, to solve the equation $4x - x^2 = (a+1)^2$ you need to write it in the standard form, find the discriminant and use the quadratic formula).

The chain of logical reasoning in solving the proposed equation is illustrated in table 2, which presents the corresponding stages in the activities of the teacher and students.

The conducted studies can be represented by a scheme-algorithm (see figure 1).

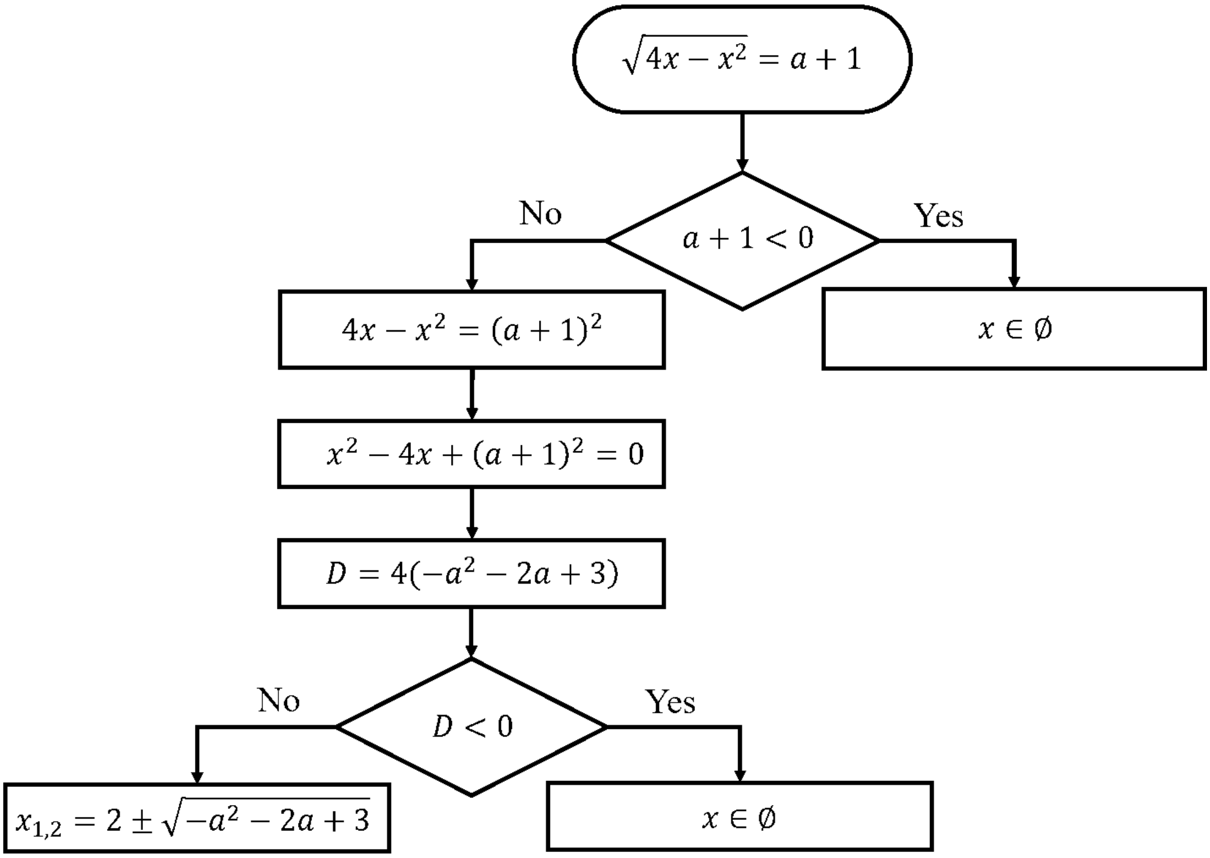


Figure 1. Scheme-algorithm of solving the task.

To illustrate the answer to the problem with the parameter, students can be asked to view a dynamic electronic workpiece `https://www.geogebra.org/m/jraxp2nd`, which discusses the values of the parameter at which the equation has solutions. On the one hand, this development illustrates the answer obtained analytically, on the other – indicates the possibility of solving the equation graphically.

Thus, figure 3 and figure 4 illustrate a case when $a \in [-1; 1)$.

figure 5 illustrates a case when $a = 1$.

3.3. Compiling a system of tasks

Compiling a system of tasks of one type that requires the selection of methods for solving them. We have formulated didactic requirements for the system of mathematical problems, which is aimed at developing students' logical thinking in teaching mathematics. The authors of the article relied on the work of scientists Khyzhniak et al. [24], Lovianova et al. [25], Bronkhorst et al. [26], Hubana [27] on this topic. Therefore, the system of mathematical problems must meet the following requirements:

Journal of Physics: Conference Series **2288** (2022) 012021 doi:10.1088/1742-6596/2288/1/012021

Table 2. Actions of the teacher and students.

Teacher	Students
1. Determine the type of equation.	1. It is an irrational equation of such type: $\sqrt[2n]{f(x)} = g(x),\ n \in \mathbb{N}$
2. Which of the functions $f(x)$ or $g(x)$ contains a parameter?	2. The parameter is contained in the function $g(x)$.
3. What transformation needs to be carried out to solve this equation in general form?	3. Both sides of the equation must be squared.
4. How to ensure the equivalence of such a transformation?	4. We must limit $g(x)$: $a+1 \geq 0$, thus $a \geq -1$.
5. Comment on the case when $g(x) < 0$.	If $g(x) < 0$ then the equation has no solutions; $a+1 < 0$; $a < -1$.Therefore, if $a < -1$ then $x \in \varnothing$.
6. What equation will we get after an equivalent transition?	6. $4x - x^2 = (a+1)^2$. This is an equation with a polynomial of the second degree on the left side. After transferring of $(4x - x^2)$ to the right side we get such a quadratic equation: $4x - x^2 - (a+1)^2 = 0$.
7. How can we solve this equation with unknown x?	7. We can use the quadratic formula.
8. Find the discriminant of this equation.	8. $D = 16 - 4(a+1)^2 = 4(-a^2 - 2a + 3)$.
9. What values can the discriminant take? How do it affect the number of roots?	9. Since the discriminant contains a parameter, it can either be greater than 0 (in this case the equation has two real roots), or less than 0 (in this case the equation has no real roots), or equal to 0 (in this case the equation has two equal real roots).
10. Find the parameter values when the discriminant is positive and write down the roots of the quadratic equation.	10. Let's consider the case when $D > 0$ that is $4(-a^2 - 2a + 3) > 0$, thus $a^2 + 2a - 3 < 0$, $a \in (-3; 1)$. Let's take into account that $a \geq -1$. Therefore, if $a \in [-1; 1)$ then $x_{1,2} = \frac{4 \pm 2\sqrt{-a^2-2a+3}}{2} = 2 \pm \sqrt{-a^2 - 2a + 3}$.
11. Find the parameter values when the discriminant is 0 and write down the roots of the quadratic equation.	11. Let's consider the case when $D = 0$ that is $4(-a^2 - 2a + 3) = 0$, thus $a^2 + 2a - 3 = 0$, $\left[\begin{array}{l} a = -3 \\ a = 1 \end{array}\right.$. Let's take into account that $a \geq -1$. Therefore, if $a = 1$ then $x_1 = x_2 = 2$.
12. Find the parameter values when the discriminant is negative and make a conclusion.	12. Let's consider the case when $D < 0$ that is $4(-a^2 - 2a + 3) < 0$, thus $a^2 + 2a - 3 > 0$, $\left[\begin{array}{l} a < -3 \\ a > 1 \end{array}\right.$. Let's take into account that $a \geq -1$. Therefore, if $a \in (1; +\infty)$ then $x \in \varnothing$.
13. Give a general answer.	13. If $a \in (-\infty; -1) \cup (1; +\infty)$ then $x \in \varnothing$; if $a \in [-1; 1)$ then $x_{1,2} = 2 \pm \sqrt{-a^2 - 2a + 3}$; if $a = 1$ then $x = 2$.

Figure 2. Link to the workpiece.

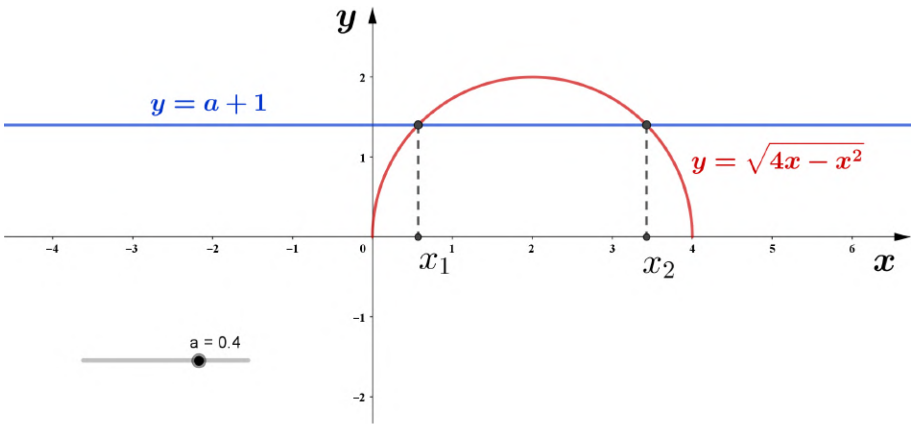


Figure 3. Graphic illustration for the case $a = 0{,}4$.

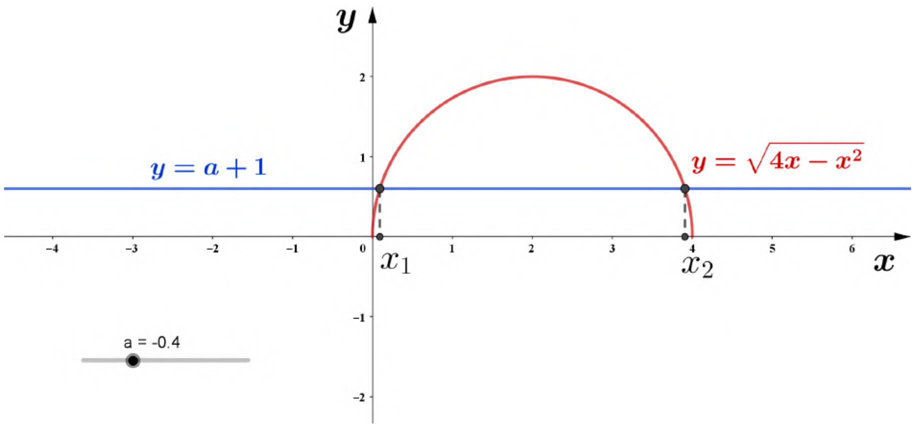


Figure 4. Graphic illustration for the case $a = -0{,}4$.

- system tasks are a learning tool that performs motivational-axiological, prognostic, and integrative functions;
- the content of tasks must comply with the principles of completeness, systematicity, and consistency;
- the tasks of the system must correspond to the content of the course and adhere to the

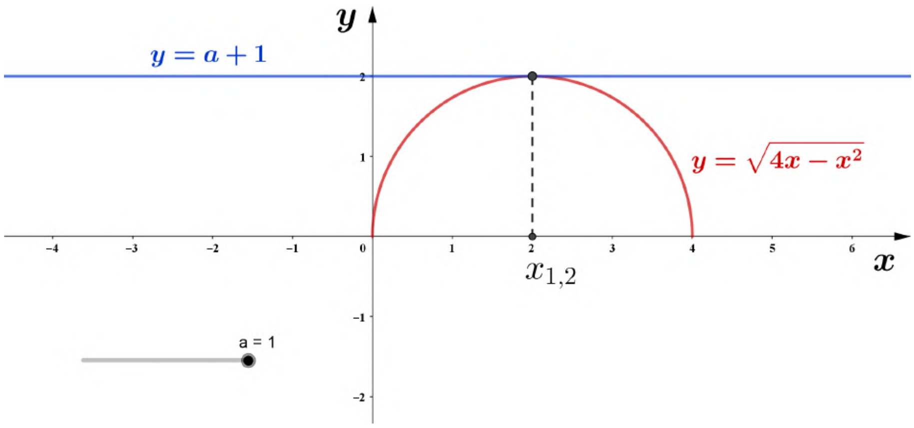


Figure 5. Graphic illustration for the case $a = 1$.

principle of gradual (linear) increase in complexity from easier and more familiar to more complex and unknown tasks and thus take into account individualization and differentiation in learning;

- tasks should provide a rational relationship between the logical and heuristic components of educational activities and thus develop students' logical thinking in two directions – the construction of algorithms and drawing up heuristic schemes;
- problems must be solved by all types of methods of this science and develop the ability to choose and apply various mathematical methods (inductive, equivalent transformations, deductive, etc.);
- each task of the system must have ideological and technical complexity and require a comprehensive and reasonably justified involvement of traditional and modern means for its solution;
- the system of tasks should teach all the procedures of creative activity.

Here is an example of a system of tasks with a parameter to the topic "Irrational equations" (see table 3).

The tasks of the proposed system are based on the principles of linear complexity and alternation of priorities of ideological and technical complexity. They provide a rational relationship between the logical and heuristic components of educational activities. For example, solving equation 1 requires adding a common factor in parentheses, equation 2 – the transition to an equivalent linear equation taking into account the domain, equation 3 – the transition to an equivalent quadratic equation taking into account the domain. Equations 4 and 5 have the same left-hand side, but the difference between the right-hand sides leads to different ways of solving these problems. In the record of problem 5 there is a root inside the root, and in problem 6 – the sum of similar expressions. Problems 8, 9, and 10 contain similar expressions, but with a different arrangement of roots, which diversifies the system of problems. The proposed system teaches all the procedures of creative activity.

4. Results

To determine the effectiveness of the introduction into the educational process of a system of problems that promotes the development of logical thinking in the teaching of mathematics, we experimented. To diagnose the level of logical thinking of students, we proposed to use the program of individual diagnostic examination of the student's personality, which is expressed in the "Diagnostic career guidance map" [28] The method reveals the mental properties of

Table 3. Task system.

Solve irrational equations with parameter a.
$2x + ax + \sqrt{x} = 0$
$\sqrt{x-a} = a$
$x = \sqrt{x^2 + 2(a+1)x + 4a} + a$
$\frac{a-1}{\sqrt{x}+1} = 1$
$\frac{a}{\sqrt{x}+1} = \sqrt{x} - 1$
$\sqrt{x - \sqrt{x-a}} = a$
$\sqrt{1 + x + \sqrt{x}} + \sqrt{1 + x - \sqrt{x}} = a$
$\frac{a+x}{\sqrt{x}+\sqrt{a+x}} = \frac{a-x}{\sqrt{x}-\sqrt{a+x}}$
$\frac{\sqrt{a+x}+\sqrt{a-x}}{\sqrt{a+x}-\sqrt{a-x}} = a$
$\sqrt[3]{\frac{a+x}{a-x}} + \sqrt[3]{\frac{a-x}{a+x}} = 2$

students, which to some extent represent the nature of the natural inclinations of students, including logical thinking. The method involves the use of specially developed by psychologists valid and reliable tests [29].

The study was based on secondary education institutions in which masters of 014 Secondary Education (Mathematics) underwent pedagogical practice: Kryvyi Rih educational complex №81, Kryvyi Rih gymnasiums №58 and №82, Kryvyi Rih secondary schools №75, №48 and №86, Oleksandrivska Secondary School of I-III Grades of Dolyna City Council, Central City Lyceum, Kryvyi Rih Pokrovsky Lyceum, Khutir Lyceum of Petrykivka Village Council, Nyvotrudivsky Lyceum of Nyvotrudiv Village Council, Orlivshchyna Lyceum of Pishchanska Village Council. The masters who were involved in the experiment attended pieces of training to get acquainted with its purpose and objectives and participated in the development of a system of tasks and methods of conducting classes using this system. Teachers were warned about the experiment and helped students with it.

The main objectives of the experiment were:

- identifying the level of logical thinking of students;
- development and implementation in the educational process of a system of problems with parameters in the study of the topic "Irrational equations", which contribute to the development of logical thinking of students;
- analysis of the results of the experiment.

Control (CG) and experimental groups (EG) were formed using the method of identifying the level of logical thinking of students [28]. At the beginning and after the experiment, a survey of 10th-grade students was conducted to determine the level of their logical thinking. Students of different educational profiles took part in the survey: mathematical, natural, philological, technological. The questionnaire questions were related to the topics of the school mathematics course [30]. Here are some examples of test tasks.

Task 1. In which of the proposed hexagons can you add a point so that both points are in the same position as in the hexagon presented in the task? The answer options:

Task 2. Observe the pattern and fill in the blank.

Task 3. Observe the pattern and fill in the blank.

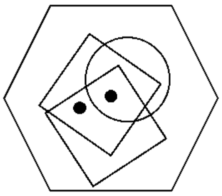


Figure 6. The illustration for task 1.

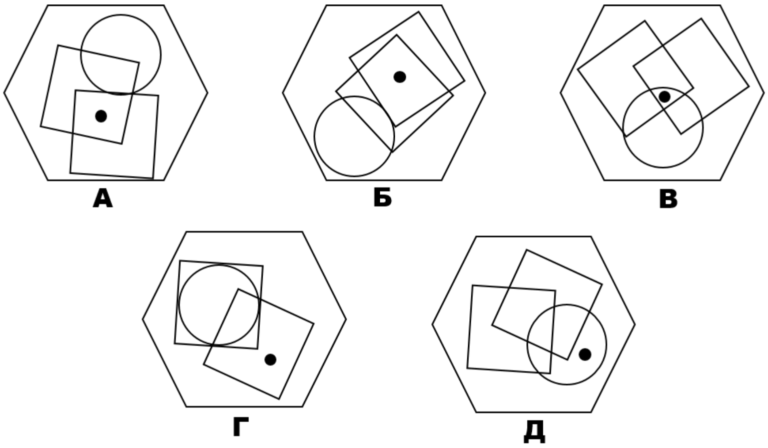


Figure 7. The answer options for task 1.

$\begin{cases} 5x - 3y = 25 \\ 3x + 2y = -4 \end{cases}$	$f(x) = x^2 + 3x - 10$
$\begin{cases} 3x - 2y = 8 \\ 5x + 3y = 7 \end{cases}$	**?**

Figure 8. The illustration for task 2.

$\sqrt{5-x} - \sqrt{2x+1}$	$-\frac{1}{2} \leq x \leq 5$
$\sqrt{5x+7} + \sqrt{x-3}$	**?**

Figure 9. The illustration for task 3.

Task 4. Observe the pattern and fill in the blank.
Task 5. Which of the numbers written in the circle is redundant?
Task 6. Observe the pattern and fill in the blank.
Task 7. Observe the pattern and fill in the blank.
Task 8. Observe the pattern and fill in the blank.
A total of 20 tasks were proposed in the test.

According to the test results, the following levels of logical thinking were identified: Zero (0 points scored), Low (1 or 2 points scored), Below average (3 or 4 points scored), Average (5 points scored), Above average (6 or 7 points scored), High (8 or 9 points scored), Highest (10 points scored). Data on the levels of development of logical thinking at the beginning of the experiment are given on diagrams (see figure 15, figure 16, figure 17, figure 18).

According to the analysis of diagrams (see figure 15, figure 16) in the characteristics of logical thinking, most students score from 2 to 7 points, which corresponds to the presence of levels

$\frac{1}{\sqrt[3]{a}}$	$\frac{\sqrt[3]{a^2}}{a}$
$\frac{b}{\sqrt{b}}$	$\sqrt{b}$
$\frac{1}{\sqrt{5}-2}$	**?**

Figure 10. The illustration for task 4.

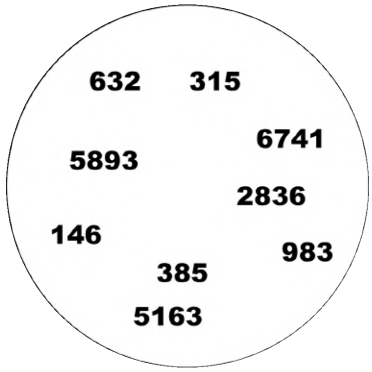


Figure 11. The illustration for task 5.

$a^2 + a$	$ab + b$	$\frac{a}{b}$
$x^2 - 6x + 5$	$x^2 - 3x + 2$	**?**

Figure 12. The illustration for task 6.

$a^2 - b^2$	$a^3 + b^3$	$a + b$
$-2x^2 + 7x - 3$	$10x^2 - x - 2$	**?**

Figure 13. The illustration for task 7.

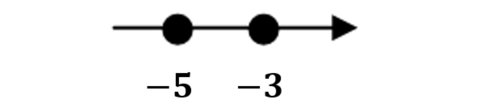
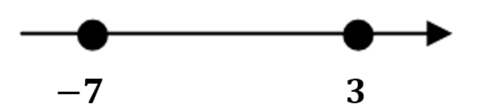
$2a\sqrt{ab}$		$4a^3b$
$b\sqrt[5]{ab^3}$		**?**

Figure 14. The illustration for task 8.

from low to above average.

Equally important is the study of the development of mental properties in students of those educational profiles in which mathematics is a non-core discipline and is studied at the basic level. Since such mental properties as logical thinking can be formed and developed only in the process of studying mathematics, and students of these profiles with mathematics in their future activities will not meet, so the responsibility for the quality of personality of high school students lies in teaching school mathematics. From this point of view, we approached the study and analysis of mental properties of students of philological and technological profiles (see figure 17, figure 18).

Thus, our research reveals problematic moments in the development of logical thinking, because in the vast majority of cases we observe a level lower than that which meets the requirements for a particular educational profile.

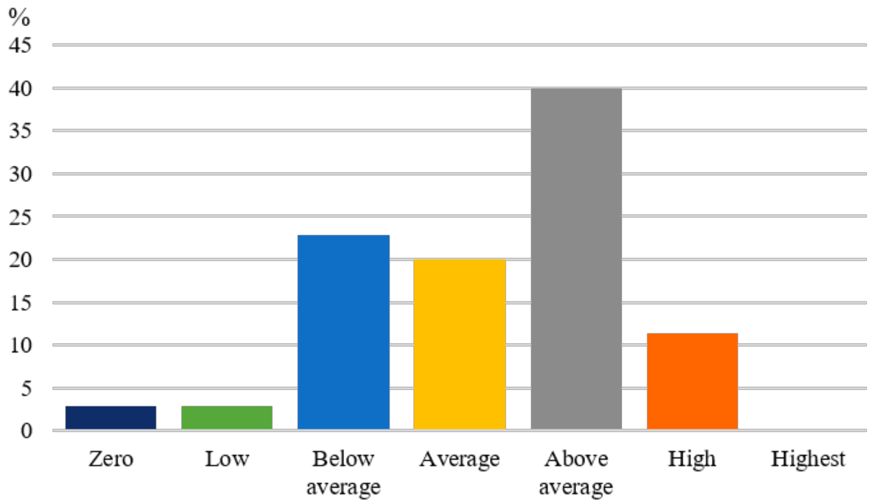


Figure 15. The level of development of logical thinking (mathematical profile).

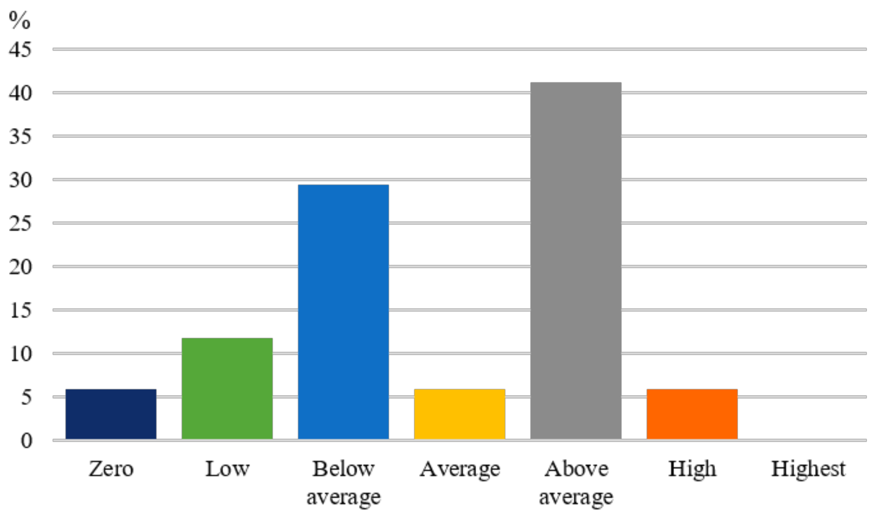


Figure 16. The level of development of logical thinking (natural profile).

The presented data necessitate the development of methodological approaches to teaching high school students mathematics in different profiles of education to increase the level of development of their logical thinking.

The experiment was conducted during the term, which studied the topic "Power function. Irrational equations"), it was attended by 367 students: 185 in CG and 182 in EG:

- the control group (CG) included students of the following schools: Kryvyi Rih educational complex №81, Kryvyi Rih gymnasiums №58, Kryvyi Rih secondary school №75, Oleksandrivka secondary school of I-III grades of Dolyna City Council, Central City Lyceum, Khutir Lyceum village council, whose algebra training was carried out according to traditional methods;
- the experimental group (EG) included students of the following schools: Kryvyi Rih gymnasiums №82, Kryvyi Rih secondary schools №48 and №86, Kryvyi Rih Pokrovsky

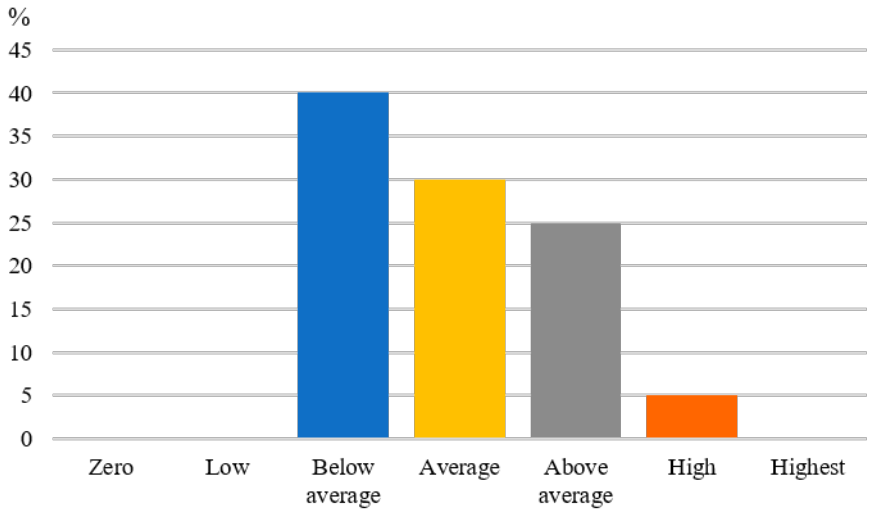


Figure 17. The level of development of logical thinking (philological profile).

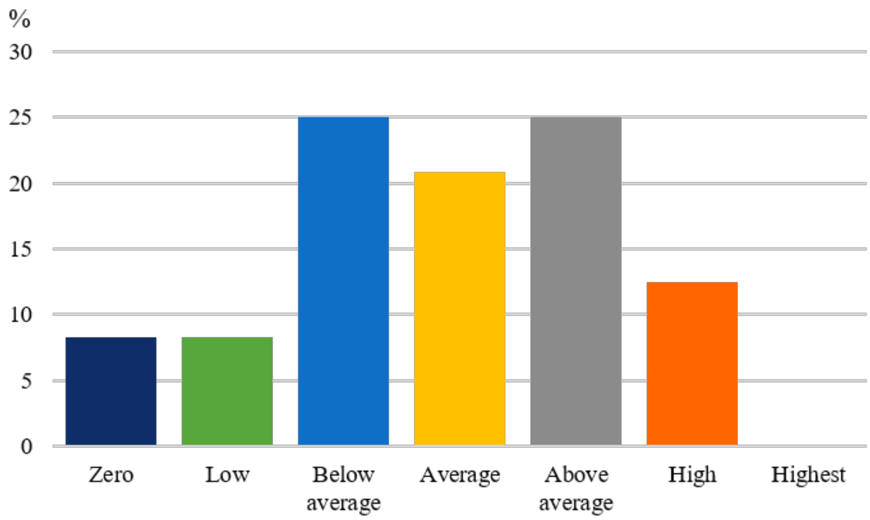


Figure 18. The level of development of logical thinking (technological profile).

lyceum, Nyvotrudivsky lyceum of Nyvotrudivka village council, Orlivshchyna lyceum of Pishchanska village council, whose algebra was taught by methods approach through offering students a system of problems with parameters in the topic "Irrational equations".

The results of comparing the distribution of students by levels of development of logical thinking at the beginning and end of the experiment are given in the table 4 and in figure 19.

Thus, statistical processing of the results confirms that the probability of distribution of students by levels of development of logical thinking in the control and experimental groups, respectively, at the end of the experiment differs significantly. And this indicates the effectiveness of a problem-based approach to teaching mathematics and the development of logical thinking of students.

Table 4. The results of the experiment.

Level	The number of students (in %)			
	The beginning of the experiment		The end of the experiment	
	EG	CG	EG	CG
Highest	0	0	1,64	0,33
High	11,48	7,95	14,75	8,28
Above average	40,0	35,1	44,92	36,42
Average	20,0	18,87	18,36	21,19
Below average	22,62	27,82	19,34	30,46
Low	2,95	5,96	0,66	2,32
Zero	2,95	4,3	0,33	1
T-criterion value	8,5518		22,9004	
Result for $\alpha = 0{,}05$	$T_{emp} < x_{1-\alpha} = 11{,}0705$		$T_{emp} > x_{1-\alpha} = 12{,}5916$	

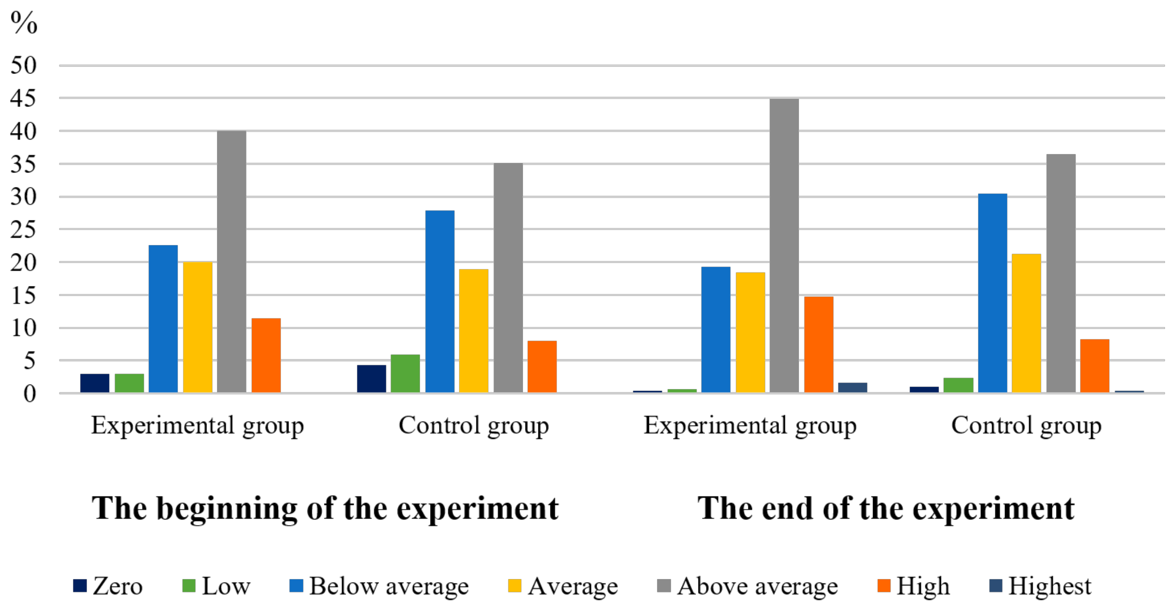


Figure 19. Comparison of experimental results.

5. Discussion

The idea of developing logical thinking of high school students in teaching mathematics was confirmed by the statements of scientists Bakhy et al. [6] that learning is an important factor in the development of logical thinking. In this aspect, researches of Lovianova et al. [25], Davidov [31], Campbell and Yeo [32] are also indicative, which indicates that the mastery of mental operations can not be separated from the learning process. We believe that individual psychological features in terms of the development of logical thinking still deserve attention. The study took into account the indicators of a qualitatively new level of development of thinking of high school students, identified by Kabanova-Meller [33]: independent transfer of generalized methods of an educational activity (choice of problem-solving method, combination of methods); change of the motivational side of mental activity and formation of stable cognitive interests;

changing the nature of the mental activity, developing its overall style.

Peculiarities of high school students' thinking, highlighted by Rohaeti et al. [14] and Davidov [31], clearly illustrate the need for systematic consideration of problems with elements of research. For example, solving a problem with a parameter, the student demonstrates the depth of thinking – the ability to identify essential features in the study of completely new material and in solving problems; latitude – the ability to retain in memory a set of selected essential features; flexibility – the ability to deviate from the usual, stereotypical ways of thinking and look for new, original ways; awareness – the ability to convey in graphs, models, diagrams, words, purpose and result of thinking; independence – the ability to set goals, put forward hypotheses; criticality – the ability to objectively assess their own and others' opinions; activity – determination and energy in the process of solving specific problems.

The authors of the article position the problem approach to teaching mathematics as a method of developing logical thinking of high school students. This position is confirmed by the research of Podgoretskaya [34], Jiang [35], which emphasizes that the development of logical thinking must be provided with special pedagogical conditions, implemented in certain methods and approaches to learning, including a gender approach. In this case, the tasks offered by the teacher in mathematics lessons should be not only reproductive (aimed at consolidating theoretical knowledge or practice) but also creative, research, problem-based. This thesis is consistent with studies by Juandi and Tamur [36], which provide convincing statistics on the effectiveness of problem-oriented learning in the formation of mathematical problem-solving skills (MPSS).

The idea of using a problem-based approach to the development of the personal qualities of applicants is confirmed in the study of Vlasenko et al [13]. Thus, scientists consider problems in elementary mathematics as a means of developing critical and creative thinking of future mathematics teachers. We are talking about the so-called. rich-problems (in particular, open-ended Problems), which have an indefinite condition or several solutions depending on the interpretation of the condition, as well as integrative problems (Integrative Problems). , especially for high school students to generalize and systematize knowledge.

The effectiveness of the problem approach in teaching a certain topic of the school course of mathematics and the development of logical thinking is determined by the quality and methodological validity of the corresponding system of problems.

In developing the requirements for the system of problems, the authors relied on the research of scientists in the field of methods of teaching mathematics. In particular, the conclusions of Bronkhorst et al. [26], which emphasizes that the system of cognitive tasks should cover all types of aspect problems; to be solved by all types of methods of the given science; teach all the procedures of creative activity; adhere to the principle of gradual increasing complexity; take into account the methodological conditions and the need for individualization. The authors of the article took into account the work of Hubana [27], which adds to the list of such requirements the need to include in the system of problems that can be solved by several methods, analysis of each method or method and the choice of the most rational, the use of different heuristic schemes. The analysis of scientists' opinions helped the authors of the article to formulate didactic requirements for the system of tasks aimed at the development of logical thinking of high school students. Namely, the authors believe that the system should consist of tasks that correspond to the content of the course and adhere to the principle of completeness, systematicity, consistency, and linear increase in complexity; solved by all types of methods of this science; provide a rational relationship between the logical and heuristic components of educational activities; have ideological and technical complexity and teach all the procedures of creative activity.

The position of the authors of the article on the consideration of problems with the parameter as one of the types of research tasks is consistent with the research of Lovianova [25], who emphasizes the value of such tasks for the development of creative intellectual skills, readiness to transfer knowledge to new situations and comprehensive vision.

The analysis of recommendations and advice of Ellis [11], Amadi et al. [12], Prastika et al. [37] allowed the authors to identify the factors that ensure the introduction of a problem-based approach to teaching mathematics as a method of developing logical thinking in high school students.

6. Conclusions

One of the indicators of the formation of logical thinking of the student is the degree of development of mental operations. The high school student has the opportunity to gradually master mental operations in learning, in particular in teaching mathematics. The study shows the implementation of the problem approach as a method of developing logical thinking of high school students on the example of studying the topic "Irrational equations".

Researchers recommend following the factors that ensure the implementation of the problem approach. Regarding the choice of a certain type of mathematical problem, researchers offer consideration of problems with parameters. This choice is since solving problems with parameters aims to form in students the skills of research, which is impossible without the involvement of mental operations of analysis, synthesis, comparison, specification, and generalization. The authors selected the method of solving problems with parameters based on the fact that there is no general scheme for solving problems with parameters. Therefore, the study presents in detail the analytical method of solving problems with parameters. One of the prerequisites for the successful implementation of the problem approach, researchers consider a system of problems of one type, which requires the selection of methods for solving them. In this regard, the article highlighted several requirements that such a system must meet. Among them: compliance of the content of tasks with axiological, prognostic, and integrative functions of learning, principles of completeness, systematicity, sequence, linear increase of complexity, individualization and differentiation in learning, development of logical thinking through mastering various mathematical methods, creative procedures and involvement of traditional and modern teaching aids. The scientific novelty of this study is the identification of factors that affect the quality and effectiveness of the task approach to teaching Mathematics and the development of schoolchildren' logical thinking, the generalization of requirements for a system of mathematical tasks. By the proposed requirements, the authors of the article proposed an example of a system of problems with parameters to the topic "Irrational equations".

The positive results of the implementation of the problem approach to teaching mathematics to develop logical thinking of high school students are evidenced by a significant increase in the experimental group of students with such levels of logical thinking above average and high. Prospects for further research, the authors see in the study of the manifestations of individual mental operations of modern adolescents, as well as in the study of the effectiveness of a problem-based approach to the development of logical thinking of students within other topics of school algebra and geometry.

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Improving the quality of mathematical education of pupils: diagnostics and analytics

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Abstract. The article considers the problem of the quality of mathematical school education in the context of pupils' ability to apply the acquired knowledge of mathematics to solve practical problems. It is established that this ability is a clear understanding and awareness of the role of mathematical knowledge in the modern world. It is manifested in the ability to explain natural and scientific phenomena, to draw sound conclusions, to understand the impact of science on human life. The results of a study in which 1849 pupils of Kyiv schools took part are presented. Their ability to apply mathematical knowledge to solve life problems has been established. Examples of mathematical problems developed for testing by specialists of the Ukrainian Center for Educational Quality Assessment are given. The typical pupils' mistakes, as well as the most successful solutions are analyzed. Pedagogical recommendations for improving the quality of mathematics education of pupils in the context of the reform of the "New Ukrainian School" are given.

1. Introduction

Mathematics can rightly be attributed to the key factors in the development of civilization. On the basis of mathematics, technical progress, computer science, computer science, etc. have been developed. Mathematical education in the system of general secondary education occupies one of the leading places, which is determined by its practical orientation, opportunities for human competence development. In addition, mathematical education is the key to personality formation, namely the development of higher processes of its thinking: judgments, inferences, comparisons, classifications, which ultimately affects the formation of intelligence. Attaching importance to this problem, in order to improve the quality of teaching and organization of education systems in the world, the International Program for Assessment of Student Achievement (PISA) includes assessment of pupils' knowledge in the field of natural sciences (*scientific literacy*), namely mathematics (*mathematical literacy*) [1]. In 2018, Ukraine took part in this survey for the first time. Actualizing the problem of mathematics education, the reform of the "New Ukrainian School" involves the development of pupils' critical and algorithmic thinking, developmental and problem-based learning, research skills, communication skills, project technology and etc. After all, it is this personal basis that enables the introduction of modern teaching technologies aimed at forming pupils' ability to apply knowledge and skills, analyze, argue and communicate effectively in the process of solving and interpreting problems in different situations.

In Ukraine, in accordance with the "Basic Standard of General Secondary Education" [2], the requirements for compulsory learning outcomes are determined on the basis of the competence approach. Key competencies include:

- mathematical competence, which involves the ability to develop and apply mathematical knowledge and methods to solve a wide range of problems in everyday life; modeling of processes and situations with the use of mathematical apparatus; awareness of the role of mathematical knowledge and skills in personal and social life;
- competencies in the field of natural sciences, engineering and technology, involving the formation of a scientific worldview; ability and willingness to apply an appropriate set of scientific knowledge and methodologies to explain the world of nature; gaining experience in studying nature and formulating evidentiary conclusions based on the information obtained; understanding the changes caused by human activity; responsibility for the consequences of such activities.

The quality of innovative forms, methods and means of teaching mathematics is the subject of research of L. Sharoff [3], S. Vijayabarathi, K. Pramila, J. Sengamalaselvi [4]; in the context of the Covid-19 pandemic there are researches of S.A. Husain, N.A.E.M. Manan, V. Goergeshua [5], E.J. Sintema [6]. In the researches of Mailizar, A. Almanthari, S. Maulina, S. Bruce [7] the barriers to the implementation of distance learning of mathematics by means of digital technologies are identified, the main challenges facing the participants of the educational process (quality of education, interest in mathematics, etc.) are highlighted. It should be noted that the quality of mathematics education in the use of digital technologies is being studied by a number of scientists. Thus, M. Bano, D. Zowghi, M. Kearney, S. Schuck, P. Aubusson [8] presented an analysis of more than 60 studies of mobile learning in mathematics. M. Skryabin, J. Zhang, L. Liu, D. Zhang [9] have established the impact of digital technology on the quality of mathematics education at school. E. Makarova, B. Aeschlimann, W. Herzog [10] revealed the problem of gender stereotypes on the quality of study of natural sciences and mathematics. In a study by J.P.J. Van der Beek, S.H.G. Van der Ven, E.H. Kroesbergen, P.P.M. Leseman [11] the connection between the level of achievements in mathematics and the emotional state of a person is traced. Various aspects of the implementation of STEM-education are presented in studies by R. Christensen, G. Knezek, T. Tyler-Wood [12], S. Chachashvili-Bolotin, M. Milner-Bolotin, S. Lissitsa [13]. Important in the context of our study is the experience of M. Shield, S. Dole [14] on the development of textbooks in mathematics in the context of developing practice-oriented tasks. In recent years, our country has taken a number of initiatives aimed at improving school education in general and mathematics in particular, among them are:

- The Concept of implementation of state policy in the field of reforming general secondary education for the period up to 2029 "New Ukrainian School", 2016 [15];
- The Concept of development of science and mathematical education (STEM-education), 2019 [16];
- announcement of the 2020/2021 academic year as the Year of Mathematical Education in Ukraine [17].

Despite the above measures that are being implemented or have already been implemented in the educational process, the issue of the quality of mathematical training of school pupils remains extremely relevant. The outlined problem acquires special significance for Kyiv educational institutions, which usually serve as a reference point for the functioning and development of the education system for other regions of the country. However, according to preliminary results of the evaluation of the quality of education, the capital's general secondary education institutions have certain problems in the context of science and mathematical training of pupils.

This encourages the scientific community to modernize and update mathematical training in school in accordance with the leading ideas of the concept of "New Ukrainian School", which among the key competencies necessary for successful self-realization in society, defines mathematical competence.

2. The aim of research

The purpose of the study is to analyze the results of pupils' diagnostics on the ability to apply mathematical acquired knowledge to solve practical problems, to develop recommendations for improving the quality of mathematics education at school.

3. Methodology

The respondents were 15-year-old pupils from schools in Kyiv. In most countries, it is that age when pupils graduate from general school, faced with a choice of profession and future life path in general. The mathematical test was prepared by the staff of the Ukrainian Center for Educational Quality Assessment. The test was prepared in accordance with the requirements of the International Program for Assessment of Student (Pupil) Achievement PISA [1]. The test consisted of 10 tasks, which took 20 minutes. The semantic block of the test consisted of the following topics: "Numbers and expressions", "Equations and inequalities", "Functions", "Triangles, quadrilaterals, circles", "Vectors and coordinates".

Pupils were offered tasks of various forms:

- task with the choice of one correct answer. Each task had a basis and four possible answers, of which only one was correct. The task was considered completed if the test participant chose and correctly marked the answer;
- the matching task had a base and two columns of information marked with numbers (left) and letters (right). Execution of the task involved establishing a correspondence (formation of "logical pairs") between the information marked with numbers and letters. The task was considered completed if the test participant made marks at the intersection of rows (numbers from 1 to 4) and columns (letters from A to D) in the table;
- open-ended task with a short answer.

The study was supported by the International Foundation "Renaissance" and the Embassy of Sweden in Ukraine.

4. Results and discussion

The following provisions were the guideline for the implementation of the study:

- The quality of mathematical training of the younger generation is an indicator of the readiness of society for socio-economic development, mobility of the individual in the development and implementation of modern technology, new technologies.
- Mathematical education is an important component of general education. The place of mathematics in the school system is determined by its role in the formation of educational, social, cultural and life competencies, values of civil society, pupils' personal development with a focus on continuing education, in the formation of creativity and critical thinking, creativity.
- Mathematics is one of the basic subjects of general secondary education, which provides a successful study of other disciplines, especially the subjects of the natural science cycle [18].

The study did not aim to find out how well pupils mastered the content of the school program. Their ability to use the knowledge, skills and abilities acquired at school to overcome real life difficulties and challenges was assessed. This ability is a clear understanding of the role of natural and mathematical knowledge in the modern world, the ability to explain natural and scientific phenomena, draw sound conclusions about them, understand the impact of science and technology to improve the material, intellectual and cultural environment. In this aspect, the study echoes the idea of the International Student Assessment Program (PISA), the results of which in Ukraine in 2018 confirmed the need to strengthen and modernize the mathematics education of pupils in general secondary education. The study, which took place on September 29, 2021, involved 1,849 10th graders, representing 292 Kyiv schools. They were asked to complete tasks for the 9th grade of four levels of difficulty (beginner, intermediate, sufficient and high). In addition to identifying pupils' ability to apply knowledge to solve practice-oriented problems, it was also important to assess their "residual knowledge" as part of the learning material that remains in the memory after learning the discipline and is sufficient for further study. The following results of solving mathematics problems are obtained:

- pupils gave the correct answer for 49.5% of tasks;
- pupils gave the wrong answer for 30.4% of tasks;
- pupils did not provide answers for 20.1% of tasks.

According to the results of the research, on average, each pupil correctly solved half of the tasks of a practice-oriented nature, which can be attributed to the average level of ability. Interestingly, a survey of 254 mathematics teachers of Kyiv schools found that teachers also assessed pupils' ability to apply knowledge in practice as average (see figure 1). Note that the teacher survey was conducted to identify real problems of natural and mathematical education of pupils. As we

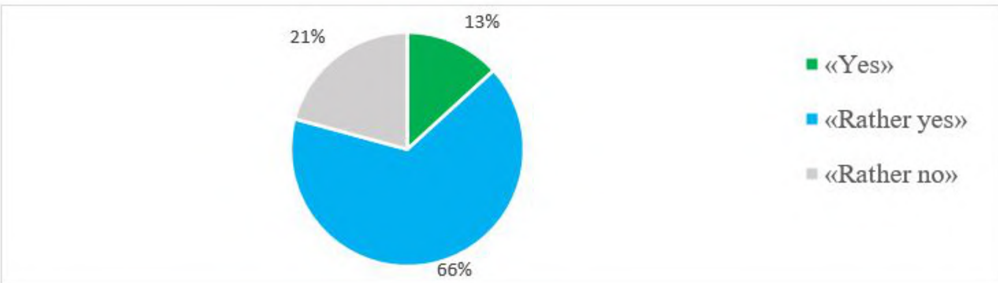


Figure 1. Distribution of teachers' answers to questions: "In your opinion, are pupils able to apply theoretical knowledge in practice to overcome various life challenges and problems?",%.

can see, only 13.2% of teachers answered yes to this question, the majority hesitated, choosing the alternative "Rather yes" (66.0%). This outlines the importance of implementing the applied orientation of academic disciplines, the development of skills to "see" mathematics in the real world, to apply the knowledge gained in school to solve everyday life needs. In this aspect, the recommendations of the International Comparative Studies (TIMSS, PISA, etc.) can be useful. The study found that 55.9% of teachers partially take them into account in their work. 34.5% of people answered in the affirmative to this question. At the same time, only 20.7% of pupils reported their experience in performing practice-oriented tasks, which indicates the need to solve the problem of improving pupils' ability to apply theoretical knowledge in practice to overcome various life challenges and problems. It is also interesting that according to teachers, the quality of mathematics education correlates with the introduction of interactive learning technologies, the use of digital tools and services, the promotion of group work to increase pupils' interest in learning mathematics. Let's analyze the success of mathematical tasks. The study found that the best pupils solved problems on the following topics: "Numbers and expressions. Numerical sets", "Functions. Formula", "Coordinates and vectors. Coordinates of the point". The range of correct answers ranged from 84.2% to 90.4%. With the help of these tasks with practical content tested knowledge of numerical sets, the ability to correlate the desired number with the numerical set to which it belongs, to express the formula of the relationship between two variables, to determine the coordinates of a point. Let's analyze some test tasks (figure 2, 3).

Task 1. What is the number of participants in a video conference?

A $\sqrt{160}$
B $\frac{200}{3}$
C 18
D -15

Figure 2. Test task 1.

Task 1 statistics show that 8.4% of respondents did not understand the conditions of the task and believed that the number of participants in the video conference could be non-integer or negative. To determine the correct answer, it was necessary to find out that the number 160 is not a square of a natural number and that the number 200 is not divisible by 3.

Task 2. 51 jars with sauces and jams were packed in gift sets, each of which contains either 3 jars with sauces (x sets) or 4 jars with jams (in sets).

Specify the correct equality.

A $3y + 4x = 51$
B $3x + 4y = 51$
C $\frac{x}{3} + \frac{y}{3} = 51$
D $12xy = 51$

Figure 3. Test task 3.

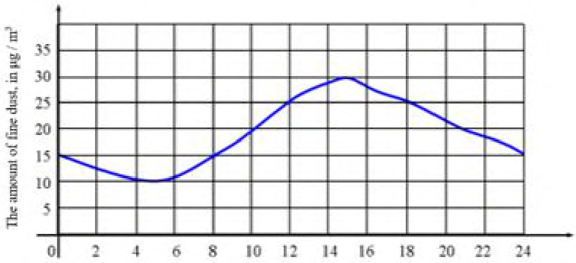
Building a mathematical model (task 2) is an important mathematical competence needed to solve text problems. One tenth of the participants did not manage to compose a letter expression with variables, which determines the number of cans of food. An important element was the drawing, which visualized the condition of the task and facilitated its implementation. Quite successfully students coped with the tasks on the topic: "Numbers and expressions. Text tasks" and "Functions. Function schedule". The range of correct answers is from 63.2% to 75.9% (figure 4, 5).

With the help of task 8 the formation of such subject competence as the ability to solve a text problem in an arithmetic way was tested. The task was to understand that an inflatable boat moves on a river at the speed of its flow and to determine the number of hours tourists spend rafting on the river, using the formula for the length of the route from rafting time and boat speed. Note that 30% of participants did not cope with this task.

Task 8. Tourists rafting down the Tisza River on inflatable boats without engines, using oars only to avoid obstacles. The length of the rafting route is 6 km. The speed of the Tisza along the entire route is 1.5 km / h. How many hours will tourists spend rafting on the river?

Figure 4. Task 8.

Task 9. Fine dust in the air is its main pollutant. The figure shows the change in the amount of this dust (in μg / m^3) in a certain area of the city during the day. Match the question (1-4) to the answer (A to D).



Question:

1. What amount (μg / m^3) of fine dust was recorded at 8.00?
2. At what time was the fine dust the least?
3. For how many hours was observed an increase in the amount of fine dust?
4. For how many hours did the amount of fine dust exceed the permissible average daily level of 25 μg / m^3?

Answers:

A 5
B 6
C 10
D 15
E 20

Figure 5. Task 9.

With the help of task 9 the formation of such subject competencies as the ability to determine was checked: the graph of the value of the function on a known argument, the value of the argument on a known function, the intervals of growth of the function. The task was to establish the relationship between time and the amount of fine dust, which is one of the factors of air pollution. To do this, it was necessary to determine the value of the function (the amount of dust recorded at this time) from the known value of the function argument (time), find the range of argument values for which the function values exceeded the specified number, specify the argument corresponding to the smallest function value. There is significantly lower performance of tasks on the following topics: "Coordinates and vectors. Coordinates of the vector", "Coordinates and vectors. The distance between two points", "Triangles, quadrilaterals, circle". The range of correct answers is from 30.2% to 46.2%. These tasks tested the ability to determine the coordinates of the vector; determine the distance between two points in the Cartesian coordinate system on the plane; determine the length of the segment by its parts, the length of the semicircular arc, the sides of the rectangle. The tasks presented practically indicative problems for determining the coordinates of the vector and its module as the distance between the school and the museum; on the correspondence between a certain value and its

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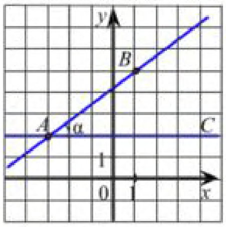
value on the example of a window frame. Less than half of the participants determined the coordinates of the vector in the figure showing its beginning and end, so they did not use the required formula. The length of the vector could be determined not only by the appropriate formula, but also by using Pythagoras' theorem to find the unknown hypotenuse by known legs (see figure 6). According to the results of the study, the most difficult tasks were: "Equations

Task 5. In a rectangular Cartesian coordinate system on the plane marked the location of the school (point A) and the museum (point B). The rectilinear road AB passes directly near the school and the museum, the rectilinear road AC passes near the school and is parallel to the x-axis (see figure).



Determine the coordinates of the vector $\overline{AB}$.

Figure 6. Test task 5.

and inequalities. Systems of equations", "Numbers and expressions. Finding the percentage of a number", "Triangles, quadrilaterals, circle. Sine, cosine, tangent of the acute angle of a right triangle. The relationship between the sides and angles of a right triangle", "Numbers and expressions. Text tasks". According to the results of the study, the range of correct answers is from 11.5% to 14.0%. With the help of these tasks the ability to compose a system of equations and find its solution was tested; find the percentage of a number; determine the angle between the lines on the plane and find the trigonometric function of this angle from a right triangle; build a mathematical model of a text problem and solve it algebraically. Only 11% of participants were able to build a mathematical model of the problem (Task 3), which is a system of linear equations, and solve it. Slightly more (14%) participants made a mathematical model for the problem in the form of a linear equation and found its root. Determining the cosine of an acute angle in a right triangle is a basic skill for planimetry, but it is difficult for most (90%) participants. The scalar product formula could also be used to determine it, but this topic is even more difficult. We present some tasks from the test (figure 7, 8).

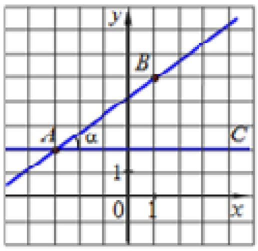
Task 3. 51 jars with sauces and jams were packed in gift sets, each of which contains either 3 jars with sauces (x sets) or 4 jars with jams (in sets). A total of 15 sets were completed.

1. Determine the number of jam sets.
2. What percentage is the number of jam sets out of the total number of sets?

Figure 7. Test task 3.

In the study, we also found the results of the test in mathematics, taking into account the attitude of pupils to the problem of applying the acquired knowledge to solve practical problems. In most cases, those pupils who feel the importance of natural sciences and mathematics (answer "Yes" to the question), received higher scores on the test results. Such pupils received an average of 9.8 points, others received 9.3 points out of 20 possible. Given that for the second year in a row the learning process takes place in a mixed format, the study was important to identify the impact of distance education as a factor in the quality of mathematics education of pupils.

Task 7. In a rectangular Cartesian coordinate system on the plane marked the location of the school (point A) and the museum (point B). The rectilinear road AB passes directly near the school and the museum, the rectilinear road AC passes near the school and is parallel to the x-axis (see figure).



Determine the cosine of the angle α between the roads AB and AC.

Figure 8. Test task 7.

The results of the survey of teachers on the scope of distance learning show that pupils of those schools where, according to teachers, all pupils are covered by distance learning, received the highest scores in testing (average scores 9.6 and 8.4, respectively). As a result of the research, it was also interesting to investigate is there a relationship between the forms of test tasks and the success of their implementation? Pupils were presented with a task with the choice of one correct answer, a task to establish compliance, an open-ended task with a short answer: a structured task and an unstructured task. It was found that pupils performed the following tasks best:

1. to choose one correct answer of the initial and intermediate levels of difficulty (68.2% of correct answers were provided);

2. to establish compliance with high to advanced levels of difficulty (provided 52.9% of correct answers).

Open-ended tasks were much more difficult for pupils: 27.2% of correct answers (structured task), 25.4% of correct answers (unstructured task) of various types of complexity other than the initial one. Thus, according to the results of the study, improving the mathematical training of pupils in Kyiv is a complex and multi-vector process that can be implemented in synergy of its various actors. Here are methodological recommendations for improving the quality of mathematics education of pupils in the context of the reform of the "New Ukrainian School":

1. Increasing the attention of teachers to the study of those learning topics that caused the greatest difficulties for pupils in the testing process: "Equations and inequalities. Systems of equations", "Numbers and expressions. Finding the percentage of a number", "Triangles, quadrilaterals, circle. Sine, cosine, tangent of the acute angle of a right triangle. The relationship between the sides and angles of a right triangle", "Numbers and expressions. Text tasks".

2. In accordance with the requirements of the State Standard of Basic Secondary Education, teachers of natural sciences and mathematics of 5-9 classes focus on revealing the competence potential of mathematics and natural sciences, in particular, focus on real practical, life problems that are relevant to pupils and motivate them to learn.

3. When assessing academic achievement, the attention have been payed to the ability of pupils to apply the acquired knowledge of natural and mathematical disciplines to solve practical problems, actively use tasks of interdisciplinary practice-oriented nature.

4. Introduce interactive learning technologies, strengthen team learning activities; use of digital

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tools for demonstrations, simulations of experiments, to promote group work, electives to increase the level of interest of pupils in the study of natural sciences and mathematics.

5. Conclusions and prospects for further research

1. The study found that pupils demonstrated an average level of ability to perform mathematical tasks of a practice-oriented nature. On average, 49.5% of tasks were completed, and the range of correct answers for different tasks ranged from 11.5% to 90.4%.

2. The most successful pupils solved the problems with the topics: "Numbers and expressions. Numerical sets", "Functions. Formula", "Coordinates and vectors. Coordinates of the point". The range of correct answers ranged from 84.2% to 90.4%. In solving these problems, the formation of the following competencies to solve problems of practice-oriented nature was tested: knowledge of numerical sets, the ability to correlate the required number with the numerical set to which it belongs; the ability to formulate the relationship between two variables; ability to determine the coordinates of a point.

3. Pupils made the most mistakes when solving problems on the following topics: "Equations and inequalities. Systems of equations", "Numbers and expressions. Finding the percentage of a number", "Triangles, quadrilaterals, circle. Sine, cosine, tangent of the acute angle of a right triangle. The relationship between the sides and angles of a right triangle", "Numbers and expressions. Text tasks". The range of correct answers ranged from 11.5% to 14.0%. With the help of these tasks the ability to compose a system of equations and find its solution was tested; find the percentage of a number; determine the angle between the lines on the plane and find the trigonometric function of this angle from a right triangle; build a mathematical model of a text problem and solve it arithmetically.

4. Recommendations for improving the quality of mathematics education at school in the context of the implementation of the reform "New Ukrainian School" (increasing the attention of teachers to the study of educational topics that caused the greatest difficulties for pupils in the testing process; introduction of interactive learning technologies, use of digital tools for demonstrations, popularization of group work to increase pupils' interest in learning mathematical disciplines; active use in the learning process of interdisciplinary practice-oriented tasks; ensuring the development of the internal quality assurance system of education) are highlighted. Methodological support for their implementation requires additional study.

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Mathematical competence and mathematical abilities: structural relations and development methodology

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Mathematical competence and mathematical abilities: structural relations and development methodology

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Abstract. In the presented work, the concept of mathematical abilities is rational as both an essential internal characteristic of mathematical competence and an immanent attribute that prevails in its personal and psychological dimension. In view of the spatial Cartesian implementation the role and place of mathematical abilities in the three-dimensional structure of the internal manifestation of mathematical competence are substantiated. The semantic and system analysis of structural components of the studied phenomenon is made. It is established that complex correlations of four structural components of mathematical abilities (system-forming, coding-formalized, cognitive-generalizing, mnemonic-generalizing) can exist with three dimensions of the external manifestation of mathematical competence (semantic-theoretical, procedural-active, personal-psychological). It is introduced that the development of mathematical abilities is provided by updating the external dimensions of mathematical competence in educational and mathematical activities. The method of developing the mathematical abilities of students is presented according to the results of the implementation of this idea and the principle of developmental continuity. The basis of this technique is the developmental-problem method of teaching mathematics as a four-level problem structure which embodies the methods of mathematical and educational (educational-theoretical) modeling, the method of ascent from the abstract to the concrete, provides a reflection of the process and results of educational and mathematical activities. Due to the problem raised in the work the authors highlight the content and results of a pilot study on the development of mathematical abilities of future mathematics teachers (freshmen and graduates). The effectiveness of the created developmental methods of mathematical education was experimentally tested.

1. Introduction

Competence of mathematical education, its reorientation from the knowledge model to the competence model determine the latest scientific rethinking of the place and role of internal resources of the individual, his individual psychological formations, which ensure the effectiveness of the formation and development of mathematical competence, allow the measurability of the structure of its internal manifestation. It is a well-established practice when mathematical competence is measured on the basis of external manifestations of the ability to act, primarily on the results of solving applied problems in Mathematics, correctly made or chosen answer. One way or another, such things as the qualities of personality and personal dimensions, which ensure successful educational and mathematical activities and serve the development of mathematical competence are neglected. There is still a lack of research on personal qualities and individual psychological formations, which are related to the internal manifestation of such competence. In fact, research on the structural links between mathematical competence and the mathematical abilities of students remains in high demand, and there is still a lack of methods for their development in educational practice.

2. Literature review

Referring mathematical competence to both subject and key competencies, researchers focus on individual psychological characteristics and personality traits:

- theoretical and practical readiness to independently and responsibly apply mathematical tools in accordance with the tasks of professional activity, mathematical competencies [1];
- integrative formation of personality, which combines mathematical and general educational knowledge, skills, abilities, experience of mathematical and general educational activity [2];
- a set of personal qualities of the student (value-semantic orientations, mathematical knowledge, skills, abilities), which allow him to effectively use mathematical knowledge and methods in future professional activities [3];
- integral quality of personality, which is the ability and willingness to use Mathematics to perform operational, epistemological and analytical functions of the teacher's activities related to education [4];
- integrated characterization of personality quality as a subject of activity in the field of Mathematics, due to which the main components of the mathematical structure are introduced (concept, relation, axioms), mathematical statements are formulated and proved (theorems), problems for construction, research and implementation of mathematical models are formulated and solved, as well as self-analysis, self-control, self-correction, self-assessment of the process and results of mathematical activities are done, their further content is planned [5];
- personal education, which characterizes the ability of the student to apply the experience of mathematical activities in solving problems [6].

The well-known methodologist-mathematician N A Tarasenkova emphasizes the dual nature of the competence of the individual (turning both outwards and inwards): "if we proceed from the established definition of competence as the ability to act on the basis of acquired knowledge (external manifestation), then a powerful layer of internal, personal factors that accelerate or slow down the process of acquiring competencies is left out of consideration" [7].Mathematical competence and mathematical abilities: structural relations and development methodology S P Semenets1, L M Semenets2, N M Andriichuk1 and O M Lutsyk2 1 Zhytomyr Polytechnic State University, 103 Chudnivska Str., Zhytomyr, 10005, Ukraine 2 Zhytomyr Ivan Franko State University, 40 Berdychivska Str., Zhytomyr, 10008, Ukraine E-mail: sergij.semenetss@gmail.com, Larisa.Semenets@ukr.net, andrnata1977@gmail.com, lutsykolha@gmail.com Abstract. In the presented work, the concept of mathematical abilities is rational as both an essential internal characteristic of mathematical competence and an immanent attribute that prevails in its personal and psychological dimension. In view of the spatial Cartesian implementation the role and place of mathematical abilities in the three-dimensional structure of the internal manifestation of mathematical competence are substantiated. The semantic and system analysis of structural components of the studied phenomenon is made. It is established that complex correlations of four structural components of mathematical abilities (system-forming, coding-formalized, cognitive-generalizing, mnemonic-generalizing) can exist with three dimensions of the external manifestation of mathematical competence (semantic- theoretical, procedural-active, personal-psychological). It is introduced

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that the development of mathematical abilities is provided by updating the external dimensions of mathematical competence in educational and mathematical activities. The method of developing the mathematical abilities of students is presented according to the results of the implementation of this idea and the principle of developmental continuity. The basis of this technique is the developmental-problem method of teaching mathematics as a four-level problem structure which embodies the methods of mathematical and educational (educational-theoretical) modeling, the method of ascent from the abstract to the concrete, provides a reflection of the process and results of educational and mathematical activities. Due to the problem raised in the work the authors highlight the content and results of a pilot study on the development of mathematical abilities of future mathematics teachers (freshmen and graduates). The effectiveness of the created developmental methods of mathematical education was experimentally tested. 1. Introduction Competence of mathematical education, its reorientation from the knowledge model to the competence model determine the latest scientific rethinking of the place and role of internal resources of the individual, his individual psychological formations, which ensure the effectiveness of the formation and development of mathematical competence, allow the measurability of the structure of its internal manifestation. It is a well-established practice when mathematical competence is measured on the basis of external manifestations of the ability to act, primarily on the results of solving applied problems in Mathematics, correctly made or chosen answer. One way or another, such things as the qualities of personality and personal dimensions, which ensure successful educational and mathematical activities and serve the development of mathematical competence are neglected. There is still a lack of research on personal qualities and individual psychological formations, which are related to the internal manifestation of such competence. In fact, research on the structural links between mathematical competence and the mathematical abilities of students remains in high demand, and there is still a lack of methods for their development in educational practice. 2. Literature review Referring mathematical competence to both subject and key competencies, researchers focus on individual psychological characteristics and personality traits: • theoretical and practical readiness to independently and responsibly apply mathematical tools in accordance with the tasks of professional activity, mathematical competencies [1]; • integrative formation of personality, which combines mathematical and general educational knowledge, skills, abilities, experience of mathematical and general educational activity [2]; • a set of personal qualities of the student (value-semantic orientations, mathematical knowledge, skills, abilities), which allow him to effectively use mathematical knowledge and methods in future professional activities [3]; • integral quality of personality, which is the ability and willingness to use Mathematics to perform operational, epistemological and analytical functions of the teacher's activities related to education [4]; • integrated characterization of personality quality as a subject of activity in the field of Mathematics, due to which the main components of the mathematical structure are introduced (concept, relation, axioms), mathematical statements are formulated and proved (theorems), problems for construction, research and implementation of mathematical models are formulated and solved, as well as self-analysis, self-control, self-correction, self- assessment of the process and results of mathematical activities are done, their further content is planned [5]; • personal education, which characterizes the ability of the student to apply the experience of mathematical activities in solving problems [6]. The well-known methodologist-mathematician N A Tarasenkova emphasizes the dual nature of the competence of the individual (turning both outwards and inwards): "if we proceed from the established definition of competence as the ability to act on the basis of acquired knowledge (external manifestation), then a powerful layer of internal, personal factors that accelerate or slow down the process of acquiring competencies is left out of consideration" [7]. Our pilot study was to find out the state of solving the outlined problem in the school educational process. Questionnaires were prepared for mathematics teachers, where they were asked to answer questions about: 1) content, features, components of mathematical abilities; 2) features of methods of development of mathematical abilities; 3) personal qualities of teachers and students that ensure the development of mathematical abilities; 4) whether students have mathematical abilities; 5) role of mathematical abilities and personal qualities of students in teaching Mathematics. Mathematics teachers believe that mathematical abilities can be attributed to both individual psychological characteristics and personal qualities. According to them, the signs of mathematical abilities are rapid mastery of mathematical knowledge, understanding of the

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5) role of mathematical abilities and personal qualities of students in teaching Mathematics.

Mathematics teachers believe that mathematical abilities can be attributed to both individual psychological characteristics and personal qualities. According to them, the signs of mathematical abilities are rapid mastery of mathematical knowledge, understanding of the teacher's explanation, logical and independent thinking, intelligence in the study of Mathematics, rapid and deep memorization of mathematical material, reduced fatigue in Mathematics. Among the key professional and personal qualities of teachers that ensure their development is called love for children, knowledge of the subject and methods of its teaching, respect for the child, individual approach to the student, knowledge of the child's psychology, ability to interest in Mathematics, patience and tact. Mathematics teachers are convinced that mathematical abilities are better developed not in lessons (while studying program material), but in extracurricular Mathematics classes. They believe that not all children are capable of Mathematics, and the percentage of such children is in the range of 10-20%. The peculiarities of the methodology of working with students capable of Mathematics include the implementation of an individual approach, increasing the number of independent works and individual tasks, rapid pace of learning program material, the leading role of theory (strict proof of theoretical facts). In their opinion, there is still a lack of scientifically sound methods for developing the mathematical abilities of students.

The purpose of the article – to establish the role and place of mathematical abilities in the dual nature of mathematical competence, to make a semantic and systematic analysis of their structural components, to highlight the methods of development of these personal formations, to experimentally test its effectiveness.

3. Methods
The following methods were used to achieve the goal: semantic-theoretical and structural-system analysis (in disclosing the content and structure of mathematical competence and mathematical abilities), abstraction and modeling (when building a Cartesian implementation), ranking (when establishing a hierarchy of indicators in the dimensions of mathematical competence), statistical (during experimental verification), semantic generalization (in the formulation of conclusions).

3.1. Theoretical substantiation of the research problem
The development of the doctrine of the dual nature of mathematical competence, based on the conceptual position of the duality of its manifestations, was embodied in the construction

Journal of Physics: Conference Series **2288** (2022) 012023 doi:10.1088/1742-6596/2288/1/012023

of Cartesian realization, the decomposition of external and internal manifestations of such competence on the basis of three dimensions [5]. It is substantiated that the three-dimensional structure of the external manifestation of mathematical competence has semantic-theoretical, procedural-active and reference-communicative dimensions (figure 1), and the three-dimensional structure of internal manifestation is represented by value-motivational, reflexive-evaluative, personal-psychological dimensions (figure 2).

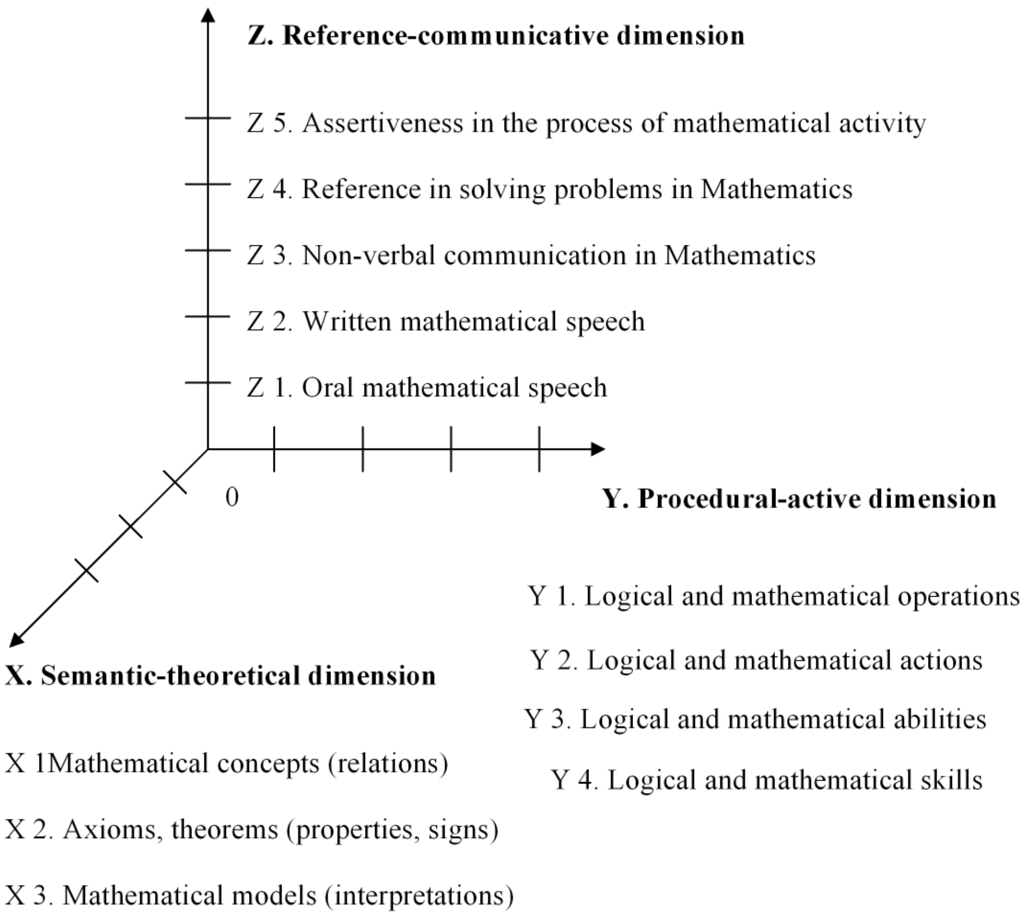

Figure 1. Three-dimensional structure of the external manifestation of mathematical competence.

Quantitative analysis of ranked indicators in each of the dimensions allowed to interpret mathematical competence as one and different fractal – a three-dimensional structure consisting of a similar three-dimensional substructure According to the results of theoretical research it is established, that the accompanying trihedron of mathematical competence dynamically determines the three-dimensional structure of its internal manifestation and at the same time establishes a connection with the three-dimensional structure of the external manifestation of such competence. For further methodological developments it is important to state that every external manifestation of mathematical competence has an internal, individual psychological and personal basis (the process of exteriorization), and the development of any of its internal manifestations is achieved through the actualization of external manifestations of competence in educational and mathematical activities (the process of internalization) [5].

In the Cartesian realization of the internal manifestation of mathematical competence in

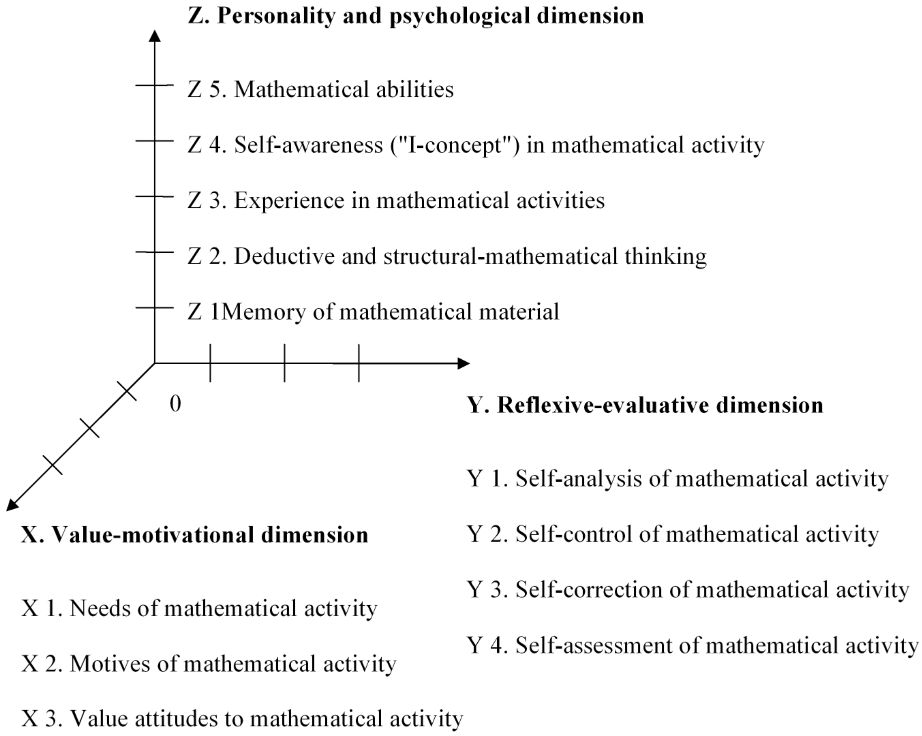

Figure 2. Three-dimensional structure of the internal manifestation of mathematical competence.

the personal-psychological dimension, the highest step is occupied by mathematical abilities (figure 2), we refer them to the subsystem in the holistic structure of the abilities of the individual, which indicates its uniqueness, serves the development of the subject of mathematical activity, enables effective, insightful and fundamental mathematical education. Thus, mathematical abilities are an immanent phenomenological characteristic, an essential feature (attribute) of mathematical competence, something that most of all represents its personal and psychological dimension. Its integrity is achieved through the unity of ranked components: mathematical abilities – self-awareness (”I-concept”) in mathematical activity – experience of mathematical activity – deductive and structural-mathematical thinking – memory for mathematical material. Let us establish correlations between the structural components of mathematical abilities and the measurements of the external manifestation of mathematical competence.

System-forming component of mathematical abilities (mathematical orientation of the mind as a personal characteristic manifested in structural and mathematical thinking, propensity and interest in the construction, study and implementation of mathematical models) correlates with three dimensions: X-dimension (semantic-theoretical) determines the subject of mathematical activity, Y-dimension (procedural-active) outlines its methods, Z-dimension (reference-communicative) specifies the socio-communicative circumstances under which the system-forming function of mathematical abilities is performed.

Coding-formalized component (ability to formalize in the process of establishing the mathematical structure of theoretical and practical material, the creation and study of sign-symbolic interpretations of problem situations) correlates with external dimensions in the following way: X-dimension determines the components of the mathematical structure, represents the set and types of mathematical models, Y-dimension establishes methods of mathematical modeling, and Z-dimension provides forms and means of interpersonal communication for the implementation of the coding-formalized function of mathematical abilities.

Cognitive-generalizing component (ability to semantic generalization of mathematical material on several levels, finding alternative (variable) and rational solutions, mental "capture" of a typical formal structure (algorithm) based on one partial case) is associated with the three-dimensional structure of mathematical competence in this way: X-dimension establishes the semantic generalizations of mathematical material, Y-dimension outlines the generalized ways of action in the process of solving typical problems, Z-dimension provides interpersonal interaction, which actualizes the cognitive-generalizing function of mathematical abilities.

Mnemonic generalization component (memorization of mathematical material at different levels of theoretical generalization; memory for typical relations (formulas), general schemes of reasoning (algorithms), structure of methods and ways of solving problems, proof and research) is reflected by the three dimensions like this: X-dimension outlines the mathematical meaning of mnemonic activity, Y-dimension determines the composition of the methods of logical-mathematical actions for memorization, Z-dimension enables interpersonal communication for the realization of mnemonic-generalizing function of mathematical abilities.

It should be noted that the phenomenon of mathematical abilities is studied in the works of both foreign and domestic researchers. Thus, the question of mathematical abilities and mathematical memory of gifted students is studied in the work of Attila Tsabo [8]. Nowadays a group of foreign authors perform the study of mathematical abilities of high school graduates [9]. Psychological and pedagogical conditions for the development of mathematical abilities of high school students are revealed in the work of O V Chugunova [10]. The problem of development of mathematical abilities of students in the New Ukrainian school is raised in the work of O R Masyuk [11].

One of the basic ideas of the presented research is the idea that the development of mathematical abilities, as well as in general, the development of personal and psychological dimension of mathematical competence should be provided at the stage of training qualified teachers. Strictly speaking, such a concept should be introduced in the system of mathematical education: mathematically competent and capable of Mathematics teacher $\Rightarrow$ mathematically competent and capable of Mathematics student. In this regard, the tasks of the presented work include experimental testing of the development of mathematical abilities of first-year students and graduate students of the specialty 014 Secondary education (Mathematics).

3.2. Experimental verification of methods of developing mathematical abilities.
The pedagogical experiment was conducted at universities in the northern, eastern, southern, and central regions of Ukraine, and members of the general population were equally likely to enter the sample. A formula was used to determine the minimum sample size

$$n = \frac{\omega(1-\omega)\cdot t^2}{\Delta^2}, \quad \text{where} \quad \omega - \text{sampling} \quad \text{ratio} \quad (0 < \omega < 1),$$

Δ – confidence interval limit error, t – argument of the Laplace function.

Confidence probability (reliability) is selected $p = 0,95$, for which the values of the argument of the Laplace integral function are found according to the tables $t = 1,96$. Taking sampling ratio $\omega = 0,5$ (for which the expression $\omega(1-\omega)$ acquires the greatest importance), confidence interval limit error $\Delta = 0,05$, the minimum sample size is calculated

$$n = \frac{0,5\cdot(1-0,5)\cdot 1,96^2}{0,05^2} \approx 384.$$

The experiment involved 396 future Mathematics teachers, and therefore, the statistical requirement for the sample size was met, and its results with a reliability of 0.95 and an error of 0.05 were extended to the whole population.

Preliminary sets of tasks were prepared, each of which involved the actualization of certain structural components of mathematical abilities. The following types of tasks have been developed:

1) to develop a structural-mathematical model of the content line (topics): basic concepts and relations $\Leftrightarrow$ properties of basic concepts and relations (axioms) $\Leftrightarrow$ denoted concepts $\Leftrightarrow$ basic theorems and methods of their proof $\Leftrightarrow$ basic types of problems and methods of solving them;
2) to build a mathematical model of an applied problem situation;
3) to solve a mathematical problem by one of the known methods, to form a generalized way of action in the process of solving typical problems;
4) match (formulas, equations and their geometric interpretations);
5) solve a problem of the Olympiad type, formulate a heuristic prescription and write down a rule-guideline for solving it. Compose your own problem.

Analysis of the obtained experimental data (figure 3) led to the conclusion that a high level of development of mathematical abilities showed only 8% of freshmen (F), sufficient - 14%, average - 32%, low - 46%.

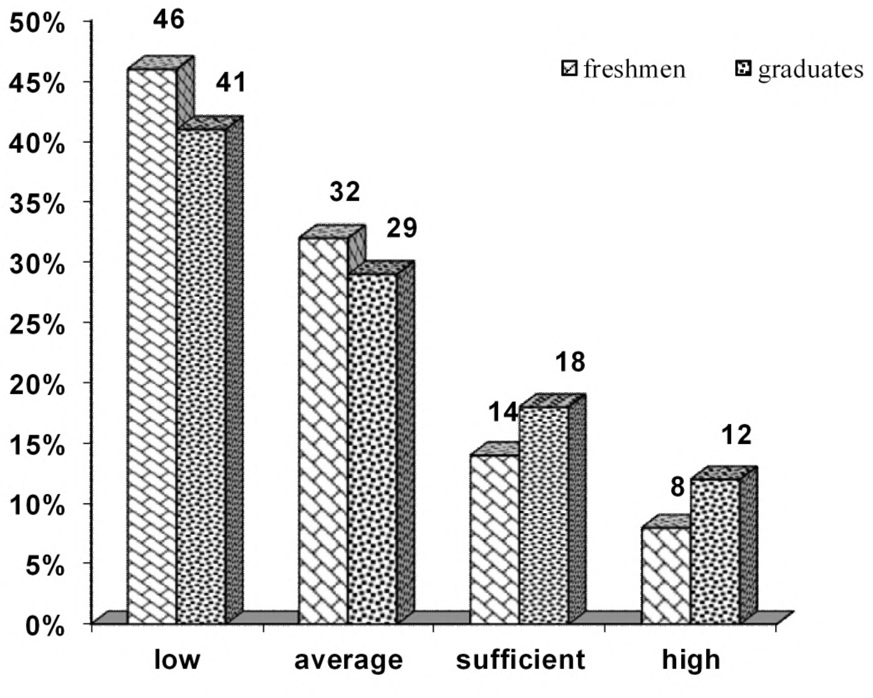

Figure 3. Levels of mathematical abilities development of future teachers of mathematics.

The overall picture of the development of these personal formations was not much better among graduate students (G): 12% showed a high level of development, 18% - sufficient, 29% - average and 41% - low.

At the end of the experiment, the methods of mathematical statistics of numerical data processing were used. The Kolmogorov-Smirnov λ-criterion was used to determine whether the two empirical distributions are subject to the same pattern in the control and experimental groups of respondents (checking for their homogeneity). The paper met the statistical requirement of the criterion - at least 100 respondents. According to the Kolmogorov-Smirnov λ-criterion, the point where the sum of the differences between the empirical distributions in the groups of F and G is the largest was found, and the significance of the differences was estimated (table 1).

The hypothesis H_0 is formulated as follows: the empirical distributions of the development of mathematical abilities of F and G do not differ. An alternative hypothesis H_1 suggested that the empirical distributions of the development of these personality formations differ.

Table 1. Calculation of the λ-criterion for comparing the empirical distributions of the mathematical abilities development of F and G.

Levels of development	Empirical frequencies		Empirical relative frequencies		Accumulated empirical relative frequencies		Difference $d = \lvert\Sigma F^* - \Sigma G^*\rvert$
	F	G	F^*	G^*	ΣF^*	ΣG^*	
Low	83	88	0,461	0,407	0,461	0,407	0,054
Average	58	63	0,322	0,292	0,783	0,699	**0,084**
Sufficient	25	39	0,139	0,181	0,922	0,880	0,042
High	14	26	0,078	0,120	1,000	1,000	0,000
Total	180	216	1,000	1,000			

Thus, $d_{max} = 0,084$. The value of the λ-criterion is calculated by the formula:

$$\lambda = d_{max} \times \sqrt{\frac{n_e \times n_k}{n_e + n_k}} = 0,83.$$

The critical value of the λ-criterion $\lambda_{kp} = 1,36$. Since $0,83 < 1,36$, then the differences between the empirical distributions are insignificant. Therefore, the hypothesis H_0 is accepted.

Thus, the results of the experiment confirmed the need to develop innovative methods of mathematical education. In the course of its development the following theoretical and methodological concepts were introduced:

1. The development of mathematical abilities of students is achieved through the actualization of external manifestations of mathematical competence in educational and mathematical activities. Its need-motivational basis is formed by the need for personal self-affirmation, professional self-determination, as well as interest in building, researching and implementing mathematical models.
2. Educational and mathematical activities have a task structure, and therefore are carried out in the process of setting and solving specific problems. The structure of the problem system is built on the principle of developmental continuity: in a certain hierarchy of problems differ in the level of semantic-theoretical generalization. Primary are the applied problems that are solved by the method of mathematical modeling, and the system-forming concept of Mathematics is the concept of "mathematical model".
3. The study of theoretical material, solving all types of problems is carried out in accordance with the general scientific method of cognition and thinking - the ascent from the general (abstract) to specific (partial). Semantic-theoretical actions (analysis, generalization, abstraction, planning, reflection) play a fundamental role in the educational knowledge of Mathematics.

4. Partial problems in Mathematics involve the step-by-step implementation of the developed educational and mathematical models (generalized methods of logical and mathematical actions) at the stage of formation of skills and abilities.
5. Reflection on the process of learning Mathematics (self-analysis, self-control, self-correction, self-assessment of the process and results of educational work in Mathematics) is an integral part of educational and mathematical activities of students. It is performed at the end of each stage of educational cognition and has the following varieties: semantic (theoretical and mathematical), procedural (methods of action in the process of solving problems), reference (type of social behavior), value (values in teaching Mathematics).
6. The present attribute of the methodology of development of mathematical abilities of students is oral and written speech, nonverbal communication, referentiality and assertiveness of behavior in educational and mathematical activities (soft skills).

In view of the above, the innovative method of teaching Mathematics implements a fundamentally different model of organization of the educational process, which differs from the established: *theory* ⇔ *problems* ⇔ *knowledge* ⇔ *control and evaluation.* An innovative didactic model of mathematical education has been introduced (figure 4).

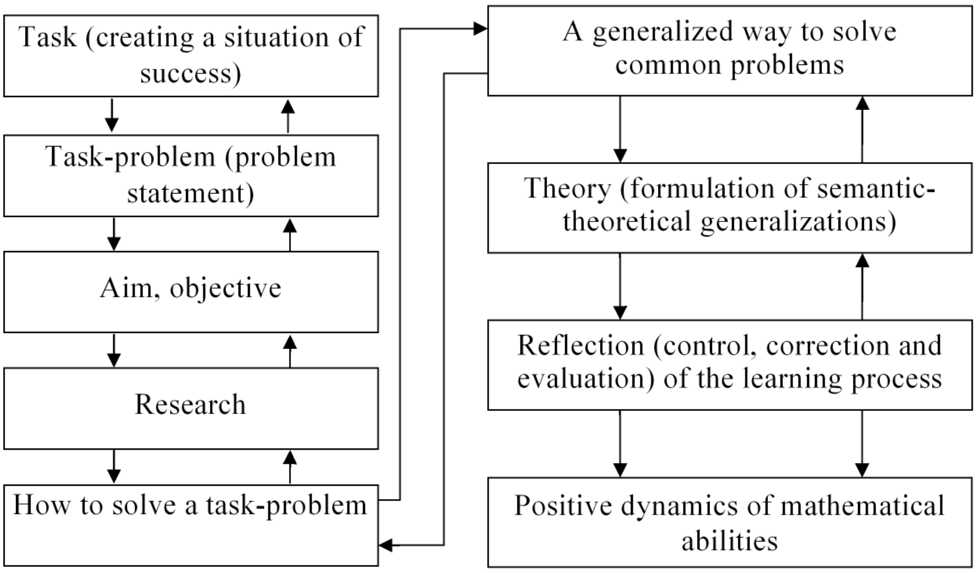

Figure 4. Innovative didactic model of mathematical education.

According to this model, a developmental and problem-based method of teaching Mathematics has been developed, which is implemented in the following stages:

I stage. Setting and solving the task(s) within the learned method of action (creating a situation of success). Monitoring and evaluation of activities performed. Creating a problem-solving situation that cannot be solved on the basis of previously discovered knowledge and established ways of acting.

II stage. Statement of an applied task-problem, its semantic analysis. Selection of the genetic relation of educational material, creation of its mathematical model. Construction of a mathematical model of a problem situation and its implementation in the process of solving a mathematical problem. Substantiation of the method of solving the problem, control of the performed actions and evaluation of their mastering.

III stage. Setting and solving a learning task. Formulation of heuristic prescriptions, construction of a general way (method) of solving typical problems, construction of its educational model as a hierarchy of educational actions. Monitoring the implementation of educational activities, their correction, assessment of the mastery of the method of solving typical problems.

IV stage. Implementation of the constructed educational model: construction and solution of a system of partial problems (applied, mathematical) according to the logic of convergence from general (abstract) to specific (partial). Control and correction of learning activities in the process of solving each task. Assessment of the level of mastering the generalized method of action.

V stage. Semantic analysis of the previous stages, control of educational activities, evaluation of the performed educational and mathematical activities. Formulation of a new task (educational-theoretical, educational-research), which involves the discovery of new knowledge (methods of action), their application in other (atypical) problem situations, the formation of a method of action of the highest level of semantic theoretical generalization. Planning the content of further educational and mathematical activities.

Control groups (CG) of students studied according to traditional methods, and in experimental groups (EG) innovative methods of teaching Mathematics were introduced. The types of tasks, as well as their level of complexity were the same for students regardless of the year of study. The experiment involved control sections of the results of the implementation of the methodology in the third and fifth years of study.

The analysis of the initial sections led to the conclusion that the levels of development of mathematical abilities in CG and EG do not differ. Thus, at the beginning of the formative stage of the pedagogical experiment, the control and experimental groups of students were homogeneous (table 2). The results of control sections showed the impact on the development of mathematical abilities of innovative methods (table 3).

19% of EG respondents showed a high level of development of mathematical abilities, 24% - sufficient, 31% - average, and 26% of respondents had a low level of development. Thus, 74% of EG students found not less than the average level of development of mathematical abilities. There was a general tendency to reduce the number of students with low and medium levels of development, and the most significant changes occurred at a sufficient level of development (12% more than freshmen). According to the results of processing experimental data, it was found that in 58% of senior students of CG the level of development of mathematical abilities was not below average. In addition, there was a small percentage change in the number of low-level CG students, and at sufficient and high levels this figure improved by 2% and 9%, respectively. It is noteworthy that the most noticeable was the dynamics of positive changes in the mathematical abilities of EG in the third year of study (figure 5).

4. Results

According to the results of qualitative analysis of the experimental results, the following conclusions were made:

1. Compared with CG, EG graduates have better skills in structural and mathematical modeling of semantic lines of elementary (school) mathematics: they more clearly distinguish between original concepts and relationships, better possess theoretical concepts (formulate definitions), name the basic theorems and methods of their proof, highlight basic types of problems and indicate methods (ways, techniques) for solving them. Thus, in EG the signs of mathematical knowledge systematization, as well as the components of

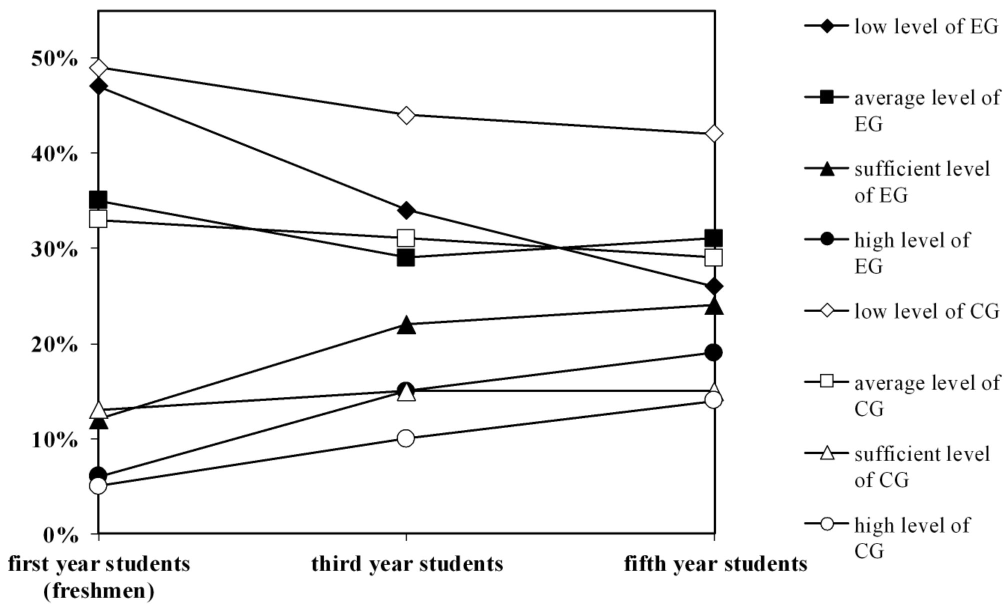

Figure 5. Dynamics of mathematical abilities of students.

structural-mathematical thinking are revealed, in comparison with CG the system-forming component of mathematical abilities is better developed.

2. EG students are better at mathematical modeling in the process of solving applied and practical problems. Correctly constructed mathematical interpretations (functions, equations, inequalities, systems, geometric figures and their combinations) are 18% more than in CG, and therefore, a coding-formalized component of mathematical abilities is better developed in the EG students.
3. The EG of graduate students better distinguishes between typical problem situations, makes generalized methods of action (algorithms) in the process of solving them. Learning modeling skills, which are closely related to the cognitive-generalizing component of mathematical abilities, are found to be 21% higher in EG than CG.
4. Memory for typical mathematical relations (formulas), general reasoning schemes (algorithms), content and structure of methods and ways of solving problems are more developed in EG students (correctly found matches are 17% more than in CG). According to the results of the introduction of experimental methods, there are positive changes in the structure of the mnemonic-generalizing component of mathematical abilities.
5. Mathematical Olympiad problems are better solved by EG students (14% more correct solutions). Based on the results of their solution, heuristic instructions are formulated, and guidelines are drawn up for use in typical problem situations.
6. The most talented students have a specific cognitive style, which includes visualization and modeling, analysis and planning, highlighting the key idea and principle, holistic (often on an intuitive level) "grasping" the structure of the problem situation. In fact, their mathematical activity is characterized by semantic generalizations and has signs of heuristics.

At the end of the pedagogical experiment, the methods of mathematical statistics of numerical data processing were used. According to the Kolmogorov-Smirnov λ-criterion, the point where the sum of the differences between the empirical distributions in the EG and CG is the largest was found, and the significance of the differences was estimated (table 2, table 3).

The hypothesis H_0 is formulated as follows: the empirical distributions of the development of mathematical abilities in CG and EG do not differ. An alternative hypothesis H_1 suggested that the empirical distributions of the development of this personality formation in CG and EG differ.

Table 2. Calculation of the λ-criterion for comparing the empirical distributions of the development of mathematical abilities in EG and CG (according to the results of the initial section).

Levels of development	Empirical frequencies		Empirical relative frequencies		Accumulated empirical relative frequencies		Difference $d = \Sigma f^*e - \Sigma f^*k$
	fe	fk	f^*e	f^*k	Σf^*e	Σf^*k	
Low	114	108	0,471	0,489	0,471	0,489	**0,018**
Average	85	73	0,351	0,330	0,822	0,819	0,003
Sufficient	29	29	0,120	0,131	0,942	0,950	0,008
High	14	11	0,058	0,050	1,000	1,000	0,000
Total	242	221	1,000	1,000			

Thus, $d_{max} = 0,018$. The value of the λ-criterion is calculated by the formula:

$$\lambda = d_{max} \times \sqrt{\frac{n_e \times n_k}{n_e + n_k}} = 0,19.$$

According to the λ-criterion, since $0,19 < 1,36$, the differences between the empirical distributions in the EG and CG at the initial section are insignificant. Therefore, the hypothesis H_0. is accepted.

Table 3. Calculation of the λ-criterion for comparing the empirical distributions of the development of mathematical abilities in EG and CG (according to the results of the control section).

Levels of development	Empirical frequencies		Empirical relative frequencies		Accumulated empirical relative frequencies		Difference $d = \Sigma f^*e - \Sigma f^*k$
	fe	fk	f^*e	f^*k	Σf^*e	Σf^*k	
Low	55	80	0,259	0,421	0,259	0,421	**0,162**
Average	66	55	0,311	0,290	0,570	0,711	0,141
Sufficient	51	28	0,241	0,147	0,811	0,858	0,047
High	40	27	0,189	0,142	1,000	1,000	0,000
Total	212	190	1,000	1,000			

Thus, $d_{max} = 0,162$. The value of the λ-criterion is calculated by the formula:

$$\lambda = d_{max} \times \sqrt{\frac{n_e \times n_k}{n_e + n_k}} = 1,62.$$

From the table we find that the obtained value $\lambda = 1,62$ corresponds to the level of statistical significance $\rho = 0,011$

We accept the critical value as follows: $\lambda_{0,05} = 1,36$. According to the λ-criterion, since $1,62 > 1,36$, then the differences between the empirical distributions in EG and CG are significant. Therefore, the hypothesis H_1 is accepted.

Thus, based on the Kolmogorov-Smirnov λ-criterion it was found that in the initial section EG and CG were homogeneous, and in the control section (after the introduction of innovative methods) the distributions began to differ. The effectiveness of developmental methods of mathematical education has been proven.

5. Conclusions

The study allows us to draw the following conclusions:

1. Mathematical abilities are the present internal characteristic of mathematical competence, its immanent attribute and the dominant of the personal-psychological dimension. They form a subsystem in the holistic structure of personality abilities, attest to its uniqueness, enable effective, insightful and fundamental mathematical education.
2. The development of mathematical abilities is achieved through the actualization of external manifestations of mathematical competence in educational and mathematical activities (the process of internalization). The existence of complex correlations of four structural components of mathematical abilities (system-forming, coding-formalized, cognitive-generalizing, mnemonic-generalizing) with three dimensions of external manifestation of mathematical competence (semantic-theoretical, procedural-psychological, personal) is established.
3. According to the results of the pilot study, it was found that the development of mathematical abilities should be provided at the stage of training qualified teachers. Levels of mathematical abilities development of freshmen and graduates of specialty 014 Secondary Education (Mathematics) are almost the same. The low level of mathematical abilities development prevails in freshmen whereas there is a slight positive dynamic of such development in graduate students. Thus, the problem of development of the named personal education in the current systems of mathematical and vocational education has a systemic and complex nature.
4. Introduction of developmental and problem-based method of teaching Mathematics, based on regulations on the actualization of external dimensions of mathematical competence in educational and mathematical activities, principle of developmental continuity of tasks, logic of ascent from abstract (general) to concrete (partial), modeling (mathematical, educational, educational-theoretical) and reflection on the process of learning Mathematics, serves to develop the mathematical abilities of students. This allows to resolve the existing contradictions of the traditionally established method of teaching Mathematics, associated with the dominance of empirical generalizations and the actualization of empirical thinking, leveling the mathematical abilities of students and neglecting the dual nature of mathematical competence.

The need to resolve these contradictions, the acute social demand for competency-oriented and developmental methods of Mathematics education determine the prospects for our further research.

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Geometric interpretation and visualization of particular geometric concepts at metric spaces study

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Geometric interpretation and visualization of particular geometric concepts at metric spaces study

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Abstract. The paper considers the issues of studying method of geometric properties of metric spaces. These questions arise when students learn the basic concepts of the metric spaces theory. Difficulty in the concepts understanding arises due to the lack of the geometric interpretation or appropriate visualization. To build a geometric interpretation of rectilinear and flat placement of points of metric space, it is proposed to build the appropriate analogues in two-dimensional and three-dimensional arithmetic Euclidean spaces. To visualize these concepts, it is proposed to use a dynamic geometric environment GeoGebra 3D. This approach allows to demonstrate both the similarity of individual geometric concepts of metric space with the corresponding concepts of Euclidean geometry, and cases of the "non-Euclidean". The study is useful for teachers and students of higher education institutions majoring in physics and mathematics. Some examples can be used in the study of basic geometric concepts by students of secondary education, in-depth study of mathematics and in various types of informal education.

1. Introduction

For the first time, students of higher education institutions get acquainted with metric spaces in the course of mathematical analysis in the study of n-dimensional Euclidean space. Later, in the course of functional analysis, metric spaces are studied in more detail, in close connection with normalized and topological spaces. One of the obstacles in understanding the new facts of the metric spaces theory is the complexity of the geometric interpretation. For example, it is very difficult to imagine a single sphere in which many points are distant from each other at a constant distance. There are many similar examples in spaces with different metrics. They significantly prevent the adequate learning of the relevant properties of metric spaces. Moreover, with a change of space metric consisting of the same elements (points), the correlation between these elements can change significantly. For example, four points that are vertices of a square in two-dimensional arithmetic Euclidean space may become rectilinear and not flat placing if the metric of space will be changed. These examples are only a small part of the facts that can cause ambiguous students' perception of the metric spaces properties, and hinder the learning. On the other hand, the modern development of geometry (especially non-Euclidean geometries), the theory of infinitely measurable metric spaces, high technology, physics, cosmology indicate a significant use of metric spaces theory in practice and confirmation of its basic principles.

This paper proposes the geometrization methods of some metric spaces properties and their visualization. In our opinion, it will contribute to a deeper mastering of the basic concepts of the metric spaces theory by students, in particular, properties and correlations that have a geometric meaning. The main means of metric space geometrization is the concept of distance between each pair of its different points. We use this concept to formalize the concept of angle, forming three different points of this space. This approach makes it possible to consider the concept of rectilinear and flat placement of points of metric space. Moreover, it will allow their geometric interpretation and visualization in the usual Euclidean spaces. On the other hand, such an interpretation will allow a clear demonstration of cases of differences between individual geometric properties of metric spaces from Euclidean geometry.

The research can be largely attributed to the subject of metric geometry [1, 2], the rapid development of which in recent years is due to its significant applications in high technology, engineering and other fields of science and technology. The characteristic feature of metric geometry is that it is based only on the concept of distance between points and properties of a set of real numbers. It significantly limits the visualization of its results, but on the other hand, it expands and generalizes the classical concepts of Euclidean geometry. Metric geometry makes it possible to consider Euclidean geometry and non-Euclidean geometries. The studying method of the elements of metric geometry by students of higher education institutions, the use of applied graphical computer tools to illustrate the results of mathematical research were considered by a number of authors, in particular, visualization of basic concepts of spherical geometry was studied in [3, 4], the visualization of inequality solutions using the system of computer mathematics Maple was considered in [5], methodological aspects of the introduction of elements of metric geometry in the school course of mathematics were studied in [6, 7].

2. Preliminary information

The distance ϱ between the two elements x_i and x_j of the set X is called a real non-negative function $\varrho(x_i, x_j)$, which satisfies the condition of commutativity: $\varrho(x_i, x_j) = \varrho(x_j, x_i)$ and the condition of triangle inequality: $\varrho(x_i, x_j) \leq \varrho(x_i, x_k) + \varrho(x_k, x_j)$ for arbitrary points x_i, x_j, x_k of this space [8]. Such a set is called a metric space with metric ϱ, and is denoted by (X, ϱ).

Methods of distance introducing between points in space (metrization methods) can be varied [9]. Its geometric properties (space geometry) largely depend on the method of space metrization. In the following we will consider several classical spaces, the metrization is based on simple concepts, and which are easy to illustrate even on the material of the school course of mathematics [7].

- Set of ordered groups of n real numbers $(x_1, x_2, ..., x_n)$, where the distance between any two sets $x(x_1, x_2, ..., x_n)$ and $y(y_1, y_2, ..., y_n)$ is solved by the formula:

$$\varrho(x, y) = \sqrt{\sum_{k=1}^{n}(x_k - y_k)^2},$$

is a metric space, which is called n-dimensional arithmetic Euclidean space, and denote R^n [10, 11].

- Let's consider the set of continuous functions on the segment $[a, b]$. This set becomes a metric space [10, 11], if the distance between the two functions $f(t)$ and $g(t)$ of the set the number is taken:

$$\varrho(f, g) = max_{t\in[a,b]}|f(t) - g(t)|.$$

Such space is denoted by $C_{[a,b]}$.

- If on the set of continuous functions on the segment $[a, b]$ for the distance between the two functions $f(t)$ and $g(t)$ of the set the number is taken:

$$\varrho(f, g) = \int_a^b |f(t) - g(t)| dt,$$

then this set becomes a metric space, which is denoted by C_L [10].

Let's consider the concept of rectilinear placement of points of the metric space. For the convenience of further records we will use the notation: $\varrho(x_i, x_j) = \varrho_{ij}$ and considered that all points of the metric space are different, i.e. the value of the distance between them is always positive. Three points x_i, x_j, x_k of the metric space are placed rectilinearly in this space, if the equality is: $\varrho(x_i, x_k) = \varrho(x_i, x_j) + \varrho(x_j, x_k)$ [12] or shorter $\varrho_{ik} = \varrho_{ij} + \varrho_{jk}$. A set of points of a metric space will be called rectilinearly placed if every three points of this set are rectilinearly placed in this space.

Under the angle formed by three points x_i, x_j, x_k of the metric space, we understand the ordered trio of these points: (x_i, x_j, x_k) and denote $\angle(x_i, x_j, x_k)$, while the point x_j will be called the vertex of the angle and pairs of points (x_i, x_j) and (x_j, x_k) - its sides [13]. For the numerical characteristic φ of the angle (angular characteristic) it is natural to take the value of the cosine of the angle of the triangle, which is from the cosines formula in the Euclidean geometry [13,14]:

$$\varphi(x_i, x_j, x_k) = \frac{\varrho^2(x_i, x_j) + \varrho^2(x_j, x_k) - \varrho^2(x_i, x_k)}{2\varrho(x_i, x_j)\varrho(x_j, x_k)},$$

or shorter

$$\varphi_{ijk} = \frac{\varrho_{ij}^2 + \varrho_{jk}^2 - \varrho_{ik}^2}{2\varrho_{ij}\varrho_{jk}}. \tag{1}$$

Thus, the specified angular characteristic makes it possible not only to obtain the condition of rectilinear placement of three points of the metric space: $\varphi_{ijk}^2 = 1$, but also the condition of "lie between" of these points [15]. In particular, the point x_j "lies between" the points x_i and x_k (or is internal to the points x_i, x_j, x_k), if the equality: $\varphi_{ijk} = -1$, if the equality $\varphi_{ijk} = 1$, then we can say that the point x_j "lies outside" the points x_i and x_k (either is external or extreme for points x_i, x_j, x_k).

Using the angular characteristic, it is possible to determine the flat placement of the points of the metric space [13]. Four points x_1, x_2, x_3, x_4 of the metric space (X, ϱ) will be called flat placed in this space if the equality is:

$$1 + \varphi_{213}\varphi_{214}\varphi_{314} - \varphi_{213}^2 - \varphi_{214}^2 - \varphi_{314}^2 = 0. \tag{2}$$

The equality (2) in Euclidean geometry, in fact, means the equality of zero volume of a tetrahedron, its vertices are located at points x_1, x_2, x_3, x_4. If every four points of some set of metric space are flat placed in this space, this set will be called flat placed in this space.

Despite the similarity of the concepts of rectilinear and flat placing of points of metric space with the corresponding concepts of Euclidean geometry, they do not always coincide. In particular, the rectilinear placing of four points of a metric space does not always follow their flat placing in this space.

3. Geometric interpretation of particular metric geometry concepts

In contrast to Euclidean geometry, the geometric interpretation of the basic concepts of metric geometry causes some difficulties, because some facts that have no place in Euclidean geometry have to be depicted in two-dimensional or three-dimensional Euclidean spaces. Here are some examples of this interpretation.

Example 1. On the segment $[0;1]$ let's consider four functions:

$$y_1 = 0, y_2 = 1, y_3 = x, y_4 = 1 - x.$$

Graphs of the functions y_1, y_2, y_3, y_4 can be represented on the coordinate plane in the space R^2 (Fig. 1).

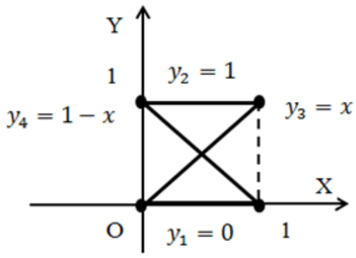

Figure 1. Images of functions y_1, y_2, y_3, y_4 in the coordinate system of space R^2.

If we consider the functions y_1, y_2, y_3, y_4 as points of the space $C_{[0;1]}$, then according to the metric of this space the distances between them will be:

$$\varrho_{12} = \varrho_{13} = \varrho_{14} = \varrho_{23} = \varrho_{24} = \varrho_{34} = 1.$$

In Euclidean geometry, such points form a regular tetrahedron with a single length of edges. Therefore, in order to interpret the mutual placing of these four points in the space $C_{[0;1]}$, it is necessary to move from their interpretation in the space R^2 to the space R^3. For convenience, we denote the points y_1, y_2, y_3, y_4, respectively, by the letters A, B, C, S. Choose a certain orientation of the tetrahedron in the space R^3. To do this, at representing the triangle ABC, point A will be placed on the coordinate start, point B- on the positive half of OX axis, point C - on the positive half of XOY plane, and point S - on the positive half of XYZ space (Fig. 2).

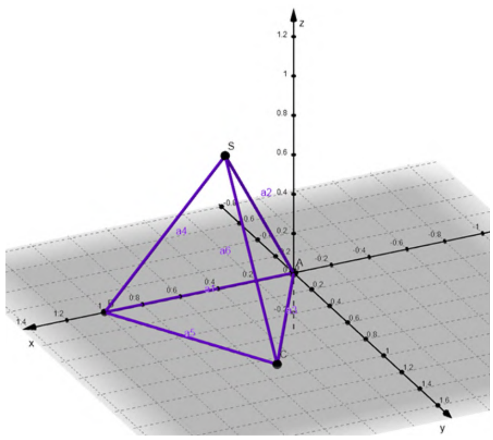

Figure 2. Location of points y_1, y_2, y_3, y_4 of space $C_{[0;1]}$ in the coordinate system of the space R^3.

This placing of points y_1, y_2, y_3, y_4 can be confirmed, using the definition of flat placing of points of metric space. To do this, we calculate by the formula (1) the angular characteristics for the angles that form the points y_1, y_2, y_3, y_4 in the space $C_{[0;1]}$:

$$\varphi_{213} = \varphi_{214} = \varphi_{314} = \frac{1^2 + 1^2 - 1^2}{2} = 0,5.$$

Putting these values into formula (2) we have:

$$1 + \varphi_{213}\varphi_{214}\varphi_{314} - \varphi_{213}^2 - \varphi_{214}^2 - \varphi_{314}^2 = 1 + (0,5)^3 - (0,5)^2 - (0,5)^2 - (0,5)^2 \neq 0.$$

Therefore, the points y_1, y_2, y_3, y_4 are not flat placing in the space $C_{[0;1]}$.

The image in Figure 2 was obtained using the dynamic geometric environment GeoGebra 3D. In this environment, it is possible visually make sure that the points y_1, y_2, y_3, y_4 are not really flat placing by rotating the coordinate system. The coordinate system is rotated so that the points A, B, C, S can be observed from a point on the XOY flat (Fig. 3).

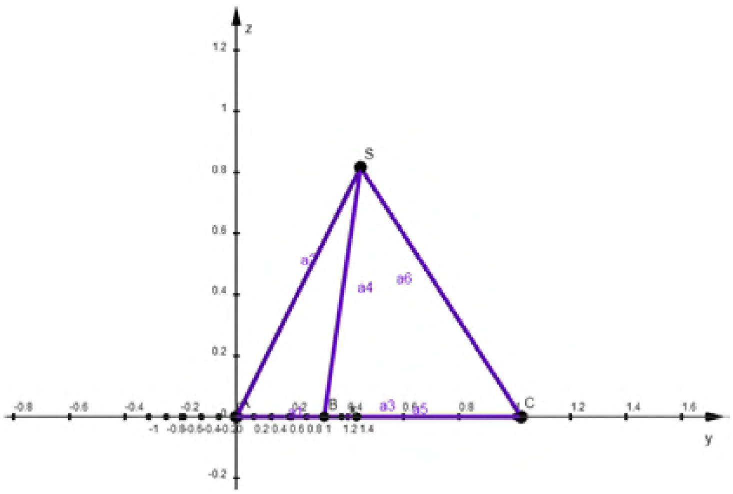

Figure 3. Placement of points y_1, y_2, y_3, y_4 when rotating the coordinate system.

If we consider the functions y_1, y_2, y_3, y_4 as points of the space C_L, according to the metrics of this space, the distances between them will be:

$$\varrho_{12} = 1; \varrho_{13} = \varrho_{14} = \varrho_{23} = \varrho_{24} = \varrho_{34} = 0,5.$$

At such distances between these points, their mutual placing cannot be represented in Euclidean geometry. They cannot lie on one line (points y_1, y_3, y_4 form an equilateral triangle). These points cannot lie in the same flate, because the points y_1, y_2, y_3, are placed rectilinearly ($\varrho_{13} + \varrho_{23} = \varrho_{12}$), and the points y_1, y_2, y_4 are placed rectilinearly ($\varrho_{14} + \varrho_{24} = \varrho_{12}$), so the points y_3 and y_4 coincide, although the distance between them is positive. In addition, a tetrahedron cannot be constructed from the points y_1, y_2, y_3, y_4, because in any orientation its three vertices will be rectilinear placed.

It is possible to construct an interpretation of such placing using a sphere in the space R^3. The points y_1, y_2, y_3, y_4 will be placed on the hemisphere of radius $\frac{1}{\pi}$. Let's take the length of the arc of the great semicircle that connects these points for the distance between a pair of points on the hemisphere (Fig. 4).

In this interpretation, the points y_1 and y_2 will be the ends of the large circle diameter, its length is two units. The points y_3 and y_4 will lie in the middle of the two semicircles connecting

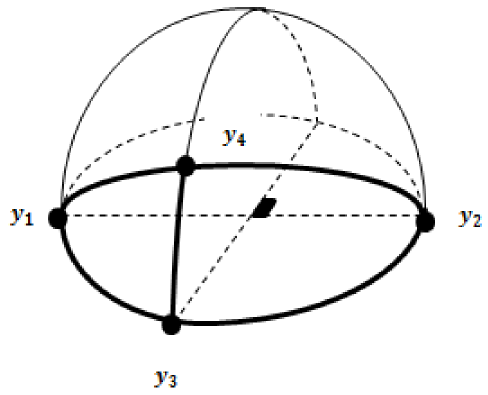

Figure 4. Interpretation of the location of points y_1, y_2, y_3, y_4 of the space C_L in the space R^3.

the points y_1 and y_2. Moreover, the points y_1, y_3, y_4, as well as points y_2, y_3, y_4, will form equilateral spherical triangles.

Example 2. On the segment $[0;1]$ consider the following functions: $y_1 = x$, $y_2 = -x$, $y_3 = -x+1$, $y_4 = x-1$ (Fig. 5).

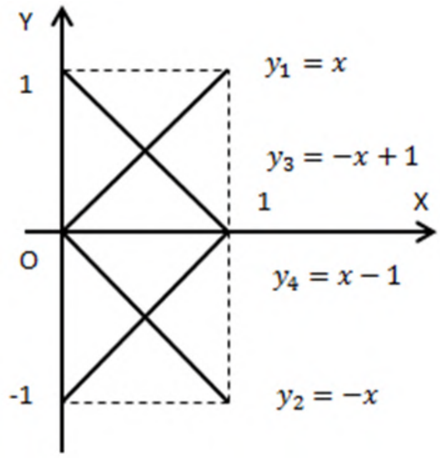

Figure 5. Images of functions y_1, y_2, y_3, y_4 in the coordinate system of space R^2.

The study [7] shows the functions y_1, y_2, y_3, y_4, as points of the space $C_{[0;1]}$, are rectilinearly placing in this space. Its peculiarity is each of these points "lies between" some of them. In the Euclidean geometry, among the four rectilinear points, two of them will necessarily be "extreme" and two – "internal" [16]. Moreover, unlike the Euclidean geometry, the points y_1, y_2, y_3, y_4 will not be flat placing in the space. Indeed, we find the distances between these points by the metric of space $C_{[0;1]}$:

$$\varrho_{12} = 2; \varrho_{13} = \varrho_{14} = \varrho_{23} = \varrho_{24} = 1; \varrho_{34} = 2.$$

Now, by the formula (1) we find the numerical characteristics of angles that have a vertex, such as point y_1:

$$\varphi_{213} = \frac{\varrho_{12}^2 + \varrho_{13}^2 - \varrho_{23}^2}{2\varrho_{12}\varrho_{13}} = \frac{2^2+1^2-1^2}{4} = 1;$$

$$\varphi_{214} = \frac{\varrho_{12}^2 + \varrho_{14}^2 - \varrho_{24}^2}{2\varrho_{12}\varrho_{14}} = \frac{2^2+1^2-1^2}{4} = 1;$$

$$\varphi_{314} = \frac{\varrho_{13}^2 + \varrho_{14}^2 - \varrho_{34}^2}{2\varrho_{13}\varrho_{14}} = \frac{1^2 + 1^2 - 2^2}{2} = -1.$$

Substitute these values in the left part of formula (2):

$$1 + \varphi_{213}\varphi_{214}\varphi_{314} - \varphi_{213}^2 - \varphi_{214}^2 - \varphi_{314}^2 = 1 + (-1) - 1^2 - 1^2 - (-1)^2 \neq 0.$$

Therefore, the points y_1, y_2, y_3, y_4 are not flat placing in the space $C_{[0;1]}$.

If students are asked to give a geometric interpretation of Example 2 in the space R^2, it can cause difficulties, because in this space a straight line always belongs to the flate. However, such an interpretation is possible if the distance between the points in the space $C_{[0;1]}$ is the length of some arc of the line connecting these points. For example, to show the mutual placing of points y_1, y_2, y_3, y_4 in the space R^2, we place them on a circle of radius $\frac{2}{\pi}$, and for the distance between a pair of these points we can take the length of the smaller of the two arcs connecting these points (Fig. 6).

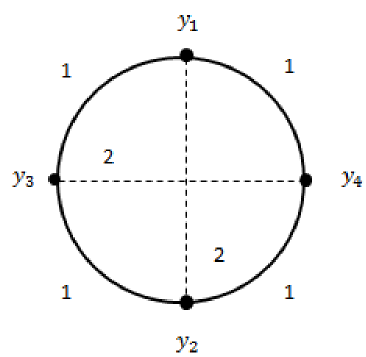

Figure 6. Interpretation of the rectilinear placement of points y_1, y_2, y_3, y_4 of the space $C_{[0;1]}$ in the space R^2.

The fact the points y_1, y_2, y_3, y_4 are not flat placing in the space $C_{[0;1]}$ can be conveniently illustrated, as in Example 1, on the hemisphere of radius $\frac{2}{\pi}$ in the space R^3 (Fig. 7).

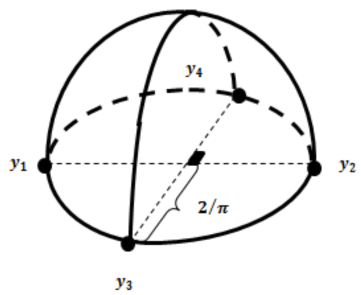

Figure 7. Interpretation of the location of points y_1, y_2, y_3, y_4 of the space $C_{[0;1]}$ in the space R^3.

In this interpretation, the points y_1, y_2, y_3, y_4 will be the ends of two mutually perpendicular diameters of a large circle. Its length is four units.

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4. Conclusions

The examples of geometric interpretation and visualization of the mutual points placing of metric space given in this paper can contribute to a deeper and more conscious perception and understanding of the metric spaces theory. The analogy of particular connections between the points of metric space with the corresponding connections in Euclidean geometry makes it possible to trace the change in the characteristic geometric properties of space at its metric changes. The use of special graphical capabilities of the corresponding software allows not only to visualize the mutual points placing of the metric space, but also to track its change at changing observation point of placing.

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Quantum-mechanical approach to simulation of molecular crystals thermal conductivity

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Quantum-mechanical approach to simulation of molecular crystals thermal conductivity

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Abstract. This article is devoted to the implementation of scientific achievements into the educational process of physics specialties students in the framework of study course "Solid State Physics". In this work, based on our previous scientific results, we present a quantum-mechanical approach that can adequately describe the temperature dependences of the dielectric crystals thermal conductivity. The basic provisions of quantum-mechanical approach are studied by students in the framework of university study course "Solid State Physics" and are based on Einstein and Debye classical models. This approach is based on the assumption that in dielectric crystals heat is transferred due to the phonons (Debye model) and thermal diffusion between the thermally activated neighboring quantum mechanical oscillators directly from site to site on a time scale of one-half of the oscillation period (Einstein model). In term of this consideration the thermal conductivity of molecular crystals are simulated in the framework of thermal conductivity model where heat is transferred by low-frequency phonons with taking into account phonon–rotation coupling, and above the phonon mobility edge by "diffusive" modes. For this purpose the theoretical temperature dependences of the isochoric thermal conductivity have been calculated numerically in the interval near or over the Debye temperature and compared with experimental results for solid C_6H_{12}, $CHCl_3$ and CH_2Cl_2. Using simple molecular crystals as an example it is shows the dualism of the nature of heat transfer processes in the temperature region of the order of the Debye temperature and above. The obtained results will be useful for implementation in the educational process in the study course "Solid State Physics" in particular for understanding the features of heat transfer in the high-temperature range of dielectric crystals existence.

1. Introduction

Implementation of the latest scientific achievements into the educational process is an important feature of modern physics education. Thus, students obtain an education that provides a general understanding of the universe nature on the basis of modern knowledge in the field of physics. In the study course of "Solid State Physics" (for example "Introduction to Solid State Physics" by Charles Kittel), the heat transfer processes are considered superficially and it is based on Debye's ideas. But the Debye model cannot adequately describe the thermal conductivity behavior of crystalline dielectrics. It is established that there are significant differences between the predictions of Debye theory and experimental results [1, 2]. In studies of molecular crystals dynamics the raise a number of problems related to the complex nature of the interaction forces between particles [1, 2]. There is no complete correspondence between the lattice dynamics of the real crystal and the theory used to describe it. The atoms of each element have a different electronic structure, in addition, molecular crystals contain more than one type of atoms, which in itself leads to quite complex systems in terms of dynamics and structure [3, 4]. The energy transfer processes are associated with continuous complex oscillations of atoms and molecules that form elastic waves propagating in the crystal. The acoustic wave propagation in solids can be described by the components of the stiffness tensor [5], which is a fourth-order tensor. Quantitative analysis of the oscillatory motion dynamics in the real three-dimensional solid is a rather difficult task, therefore in practice various approximations are widely used to simplify such analysis [6–10]. If the particles of anharmonic medium are displaced during the propagation of one wave, then for the others waves the elastic properties of the medium are already changed along the direction of their propagation [11]. Where the particles are displaced more strongly, the medium becomes more (or less depending on the deviation sign from the harmonicity) hard. This idea is the basis of Debye thermal conductivity theory [12]. Debye theory proposes a simple linear dispersion law $\omega(q) = \upsilon\mathbf{q}$ (where ω is the frequency of oscillations, υ is the speed of wave propagation, $\mathbf{q}$ is the wave vector) which does not correspond to the real dispersion relation of all interacting modes of the crystal.

Quantum theory [8] introduces the concept of phonon - a quantum of elastic wave energy that can propagate through a crystal and that is characterized by energy and direction of propagation. The phonon energy ε is determined by the frequency ω of oscillations of the elastic wave $\varepsilon = \hbar\varepsilon$ (where $\hbar$ is the Planck's constant). The wave vector $\mathbf{q}$ determines the quasi-momentum of the phonon $\mathbf{p} = \hbar\mathbf{q}$. The velocity of the phonon is determined by the group velocity υ_{gr} of the corresponding classical waves $\upsilon_{\text{gr}}=\partial\omega/\partial\mathbf{q}$. In another form ($\upsilon_{\text{gr}}=\partial\varepsilon(\mathbf{p})/\partial\mathbf{q}$) the formula is similar to the usual relationship between energy ε, momentum and particle velocity. The free propagation of waves in a harmonic approximation corresponds to the phonons motions that do not interact with each other in quantum theory. In the next approximations, the processes of phonon interaction appear. This interaction determines the mechanism of establishing thermal equilibrium in phonon gas, i.e. the mechanism of establishing the equilibrium thermal motion of phonons [8].

Special attention to experimenters and theorists is the existence region of the solid phase of dielectric crystals in the temperature region of the order of the Debye temperature and above ($T \geq \Theta_D$). The thermal conductivity corresponding to this temperature range is called high-temperature. The results of experimental research show the temperature dependences of the high-temperature thermal conductivity in dielectric crystals, which differ from the theoretically predicted 1/T dependence [1,4,10,11]. There is no uniform point of view on the mechanisms that determine high-temperature thermal conductivity therefore consistent theory of heat transfer in molecular crystals has not been created to date. As compared to atomic crystals, new types of thermal motion appear in molecular crystals that can affect on the thermal conductivity and complicate the analysis of thermal conductivity temperature dependence. The classical theoretical models of heat transfer were created mainly on the basis of studies of the simplest crystal structures - rare gas solids. As a result, the features characteristics of molecular crystals were not taken into account in them, in particular the influence of the molecular orientational motion [1, 11].

In this work, based on our previous scientific results, we present a quantum-mechanical approach that can adequately describe the temperature dependences of the thermal conductivity of dielectric crystals and can be used in educational processes of physics specialties students.

2. Approach

In thermal conductivity, the most important is the part of potential energy of the displaced atom that corresponds to members of a higher order than the second. Phonon interaction processes occur taking into account the members of the third and higher orders. It was shown that in the high-temperatures region ($T \geq \Theta_D$) the phonon interaction processes with the participation of four phonons do not have a significant effect on the thermal conductivity of rare gas solids and simple molecular crystals [1,13]. Of all the anharmonic terms, cubic ones are the most important for describing thermal conductivity. The probability of three-phonon interaction processes turns to zero if the conditions are not met [1, 11]:

$$\hbar\omega_1+\hbar\omega_2 = \hbar\omega_3. \tag{1}$$

and

$$\hbar\mathbf{q}_1+\hbar\mathbf{q}_2 = \hbar\mathbf{q}_3. \tag{2}$$

The processes of three-phonon interaction that described in the framework of the law of energy conservation (1) and the law of momentum conservation (2) are known as normal processes or N-processes. Thermal conductivity would be unlimited if N-processes were the only possible type of phonon interaction in perfect crystal. The fact that N-processes do not create thermal resistance does not mean that they do not affect heat transfer and can be neglected. When interacting with other processes, they can significantly affect the thermal conductivity [11]. Peierls showed [8] that the establishment of the phonons equilibrium frequency distribution is provided by the processes of phonon interaction, the law of conservation of energy in which is described by formula (1), and the wave vectors of phonons are related by equation:

$$\mathbf{q}_1+\mathbf{q}_2 = \mathbf{q}_3 + G. \tag{3}$$

where G is the inverse lattice vector.

The processes of phonon interaction that occur at $G \neq 0$, Peierls called Umklapp processes or U-processes. A characteristic feature of U-processes is that they change the momentum and heat transfer direction. U-processes lead to thermal resistance and ensure the establishment of an equilibrium phonon distribution. For U-processes to occur, the interacting phonons must have sufficiently large pulses (on average more than half of the maximum). At temperatures above the corresponding Debye temperature, the intensity of U-processes increases significantly and this type of phonon interaction determines the high-temperature thermal conductivity behavior [14, 15]. As the temperature decreases, the intensity of U-processes decreases. In the case of temperature decreasing, the mean free path of phonons becomes of the order of crystal size and border scattering of the phonons begins to play a significant role. In the low temperatures region ($T << \Theta_D$), this type of phonon scattering is the dominant factor in the thermal conductivity behavior of crystalline dielectrics. Any number of phonons can be in each quantum state. This means that the phonon gas is described by Bose-Einstein statistics. Since the total number of particles in such gas is not specified and is determined by equilibrium conditions, the chemical potential is zero [16]. At thermal equilibrium, the average number of phonons in each quantum state is determined by the Planck distribution function. In a dielectric crystal, phonons can be considered as rarefied gas of particles [11], and the kinetic equation is written as for ordinary gas. Note that the concept of elementary excitations (phonons) arises as a way of quantum-mechanical consideration of the collective motion of atoms and molecules in solids, but they can in no way be identified with atoms or molecules [16].

Let $N = N_g(t, r, q)$ is distribution function for phonons of the g-type (where t is time, r is the radius vector). The kinetic equation for each particle type is written as [17]:

$$\frac{\partial N}{\partial t} + \upsilon\frac{\partial N}{\partial r} = StN. \tag{4}$$

A significant difference compared to ordinary gas is that in the process of phonon interaction the number of phonons and their total quasi-momentum is not preserved. The only law of conservation valid for all types of phonon-phonon interaction is the law of energy conservation [17]:

$$\sum_g \int \omega StN \frac{d^3q}{(2\pi)^3} = 0. \tag{5}$$

Multiplying expression (5) by ω and integrating it by $\mathrm{d}^3\mathbf{q}$, the sum of g we obtain the law of conservation of energy in differential form:

$$\frac{\partial E}{\partial t} + div\ h = 0. \tag{6}$$

where the density of thermal energy of the crystal E and the density of its flow $\mathbf{h}$ are given by the following expressions:

$$E = \sum_g \int \omega N \frac{d^3N}{(2\pi)^3}. \tag{7}$$

$$h = \sum_g \int \omega \upsilon N \frac{d^3q}{(2\pi)^3}. \tag{8}$$

The collisions integral (4) must take into account all the processes that occur as a result of the interaction of g-type phonons with other phonons. The collision integral is the difference in the number of processes of phonon emergence and annihilation. As already mentioned, the main contribution to thermal conductivity is given by three-phonon interaction processes $[1, 11, 13]$. Taking into account only the processes of three-phonon interaction, the integral of collisions is written as follows [17]:

$$\begin{gathered} StN = \int \left\{ \tfrac{1}{2} \sum_{g_1 g_2} \omega\left(q_1, q_2, q\right) \delta\left(\omega - \omega_1 - \omega_2\right) \left[\left(N+1\right) N_1 N_2 - N\left(N_1+1\right)\left(N_2+1\right)\right] + \right. \\ \left. \sum_{g_1 g_3} \omega\left(q, q_1, q_3\right) \delta\left(\omega_3 - \omega - \omega_1\right) \left[\left(N+1\right)\left(N_1+1\right) N_3 - N N_1 \left(N_3+1\right)\right] \right\} \tfrac{d^3 q_1}{(2\pi)^3} \end{gathered} . \tag{9}$$

where $N_1 \equiv N_{g1}(q_1)$, $\omega_1 = \omega_{g1}(q_1)$, $N_2 \equiv N_{g2}(q_2)$, $\omega_2 = \omega_{g2}(q_2)$, $\ldots$, $\ldots$. The first term in parentheses corresponds to the direct and reverse processes:

$$(gq) \Leftrightarrow (g_1 q_1) + (g_2 q_2)\,. \tag{10}$$

$$q_2 = q - q_1 - G. \tag{11}$$

In subintegral expression (9), the products of NN_1N_2 and NN_1N_3 are mutually reduced. At the equilibrium phonon distribution, the integral of collisions (9) becomes equal to zero. In the absence of U-processes, the energy and quasi-momentum of phonons are preserved. In this case, the equilibrium is not only the function of phonon distribution, but also the functions corresponding to the translational motion (drift) of the phonon gas. Heat is transferred in the presence of temperature differences in different regions of the crystal, therefore for determine the thermal conductivity it is necessary to write the kinetic equation in the presence of small temperature gradient in crystal [16]. The phonon distribution function can be written as:

$$N(r, q) = N^0(q) + \delta N(r, q). \tag{12}$$

where $N^0(q)$ is the equilibrium distribution function of phonons, $\delta N(r, q)$ is the correction to the equilibrium distribution function caused by the temperature gradient. The kinetic equation takes the form [17]:

$$(\upsilon \nabla T)\, \frac{\partial N^0}{\partial T} = \mathrm{I}\left(\delta N\right). \tag{13}$$

where $\mathrm{I}(\delta N)$ is the linearized collisions integral.

In quantum theory, the presence of heat flow indicates the difference of phonons distribution from equilibrium distribution [17]. In dielectric crystals, the main part of the heat flow is transferred by phonons [1, 8, 9, 11, 18]. That is, the thermal conductivity of dielectric crystals is determined by the deviation degree of the phonon distribution from equilibrium. As a rule, deviations from the equilibrium distribution of phonons are expressed in terms of relaxation time or mean free path of phonons [9]. Thermal conductivity Λ is described by Fourier law (a linear relationship between the heat flow density $\mathbf{h}$ and the temperature gradient ∇T):

$$\mathbf{h} = -\Lambda \nabla T. \tag{14}$$

Under thermal equilibrium conditions at temperature T, the number of excited phonons (phonon modes) with wave vector $\mathbf{q}$, polarization s, and angular frequency ω is described by the ordinary Planck function [1, 11]:

$$N^0(q) = \left[\exp(\hbar\omega/k_B T) - 1\right]^{-1}. \tag{15}$$

where k_B is Boltzmann's constant. At temperature gradient, the phonons move to the region of lower temperatures, restoring the equilibrium distribution of phonons. The density of stationary heat flow that generated by all oscillating modes is equal to:

$$h = \sum N(q)\hbar\omega \upsilon_{gr}(q). \tag{16}$$

Temperature gradient indicates phonon distribution that different from equilibrium distribution and which changes over time at each point of the crystal with velocity $(\partial N(q)/\partial t)_{drift}$. In steady state, the change in the number of phonons as a result of changes in heat flow is compensated by scattering processes $(\partial N(q)/\partial t)_{scat}$. Taking into account these processes, we can write the transfer equation or, in other words, the Boltzmann kinetic equation:

$$(\partial N(q)/\partial t)_{drift} + (\partial N(q)/\partial t)_{scat} = 0. \tag{17}$$

Boltzmann's equation (17) is used to describe the phonon flow kinetics [1, 2]. The solution of the Boltzmann equation is associated with significant mathematical difficulties, so different approximations are often used. Consider the solution of the Boltzmann equation using the time-relaxation approximation (τ-approximation) [1, 11]. In this approximation, it is assumed that each phonon scattering mechanism is characterized by a certain average relaxation time τ_i, which for this mode does not depend on the phonon saturation of other modes. In the relaxation method, the phonon scattering processes contribute to establishing the equilibrium phonon distribution, and the speed of distribution change is proportional to deviation from equilibrium [1, 11]:

$$\left(\frac{\partial \mathrm{N}}{\partial t}\right)_{\mathrm{scatt}} = \frac{\mathrm{N}^0 - \mathrm{N}}{\tau}. \tag{18}$$

To simplify the calculation procedure, consider that the temperature gradient exists only in one direction and the phonons move only along the Z axis. At the initial time t on a given segment of the Z axis, the number of phonons is N. After a certain period of time δt the phonons will displaced, and their number will correspond to the density of another segment,

$$\mathrm{N} - \upsilon_{gr}^{z}\delta t \frac{\partial \mathrm{N}}{\partial \mathrm{Z}}. \tag{19}$$

and

$$\left(\frac{\partial \mathrm{N}}{\partial t}\right)_{\mathrm{drift}} = \upsilon_{gr}^{z}\frac{\partial \mathrm{N}}{\partial \mathrm{T}}\frac{\partial \mathrm{T}}{\partial \mathrm{Z}}. \tag{20}$$

In the τ-approximation it is assumed that the phonon distribution does not differ much from the equilibrium one, i.e. in equation (20) $\frac{\partial \mathrm{N}}{\partial \mathrm{T}}$ can be replaced by $\frac{\partial \mathrm{N}^0}{\partial \mathrm{T}}$. Using equations (17), (18) and (20) we can write:

$$-\upsilon_{gr}^{z}\frac{\partial \mathrm{N}^0}{\partial \mathrm{T}}\frac{\partial \mathrm{T}}{\partial \mathrm{Z}}=\frac{\mathrm{N}^0-\mathrm{N}}{\tau}. \tag{21}$$

Substitution (21) in (16) gives the expression for the total heat flow along the Z axis

$$h_z=-\sum \hbar\omega\left(\upsilon_{gr}^{z}\right)^2\tau\frac{\partial N^0\partial T}{\partial T\partial Z}. \tag{22}$$

The equation for thermal conductivity is obtained by substituting in (14) the formula for the heat flow (22):

$$\Lambda=\sum \hbar\omega\left(\upsilon_{gr}^{z}\right)^2\tau\frac{\partial \mathrm{N}^0}{\partial \mathrm{T}}. \tag{23}$$

Replacing the integral sum in (23) by the integral over ω and assuming that the group velocity of phonons in all directions is the same $\left(\upsilon_{gr}^{z}\right)^2=\left(\upsilon_{gr}^{2}/3\right)$ (valid only for cubic crystals), the thermal conductivity can be written as [1, 2]:

$$\Lambda=\frac{1}{3}\int\limits_0^{\omega_{\max}}\hbar\omega\upsilon_{gr.}^2\tau f\left(\omega\right)\frac{\partial \mathrm{N}^0}{\partial \mathrm{T}}d\omega. \tag{24}$$

where $f\left(\omega\right)d\omega=\frac{3\omega^2}{2\pi^2\upsilon^3}d\omega$ is the density of phonon modes in the frequency range from ω to $\omega+d\omega$. Derived from (15) gives the following expression [1, 2, 11]:

$$\frac{dN^0}{dT}=\frac{d}{dT}\left(\frac{1}{e^{\hbar\omega/k_BT}-1}\right)=\frac{e^{\hbar\omega/k_BT}\hbar\omega/k_BT}{\left(e^{\hbar\omega/k_BT}-1\right)^2}. \tag{25}$$

Substitution (25) in (24) gives:

$$\Lambda=\frac{1}{2\pi^2\upsilon}\int\limits_0^{\omega_{\max}}\hbar\omega^3\tau\frac{\exp\left(\frac{\hbar\omega}{k_BT}\right)\hbar\omega/k_BT}{\left(\exp\left(\frac{\hbar\omega}{k_BT}\right)-1\right)^2}d\omega. \tag{26}$$

Expressing the edge frequency $\omega_{\max}$ through the Debye frequency $\omega_D=\left(6\pi^2n\right)^{1/3}$ (where $n=1/a^3$ is the number of atoms per unit volume, a^3 is the volume of a single atom (molecule)) and performing in equation (26) the replacement of $\tau(\omega)$ by $l(\omega)$, the expression for thermal conductivity (26) can be written as:

$$\Lambda=\frac{h^2}{2\pi^2\upsilon^2k_BT}\int\limits_0^{\omega_D}l_{\Sigma}(\omega)\omega^4\frac{\exp\left(\frac{\hbar\omega}{k_BT}\right)}{\left(\exp\left(\frac{\hbar\omega}{k_BT}\right)-1\right)^2}d\omega. \tag{27}$$

where $l(\omega)$ is the mean free path of phonons.

Classical models of thermal conductivity were created on the basis of simple theoretical ideas about the three-phonon interaction therefore they do not take into account the features inherent to real physical systems (molecular crystals). Unlike atomic crystals, molecular crystals are characterized by the presence of both translational and orientational oscillations of molecules as a whole. In the high temperature region ($T\geq\Theta_D$), both direct phonon-phonon scattering and the processes of thermal energy diffusion between neighboring atoms or molecules (caused by the localization of high-frequency oscillatory modes) can play an important role in heat transfer [19–22]. In molecular crystals, the localization may be the result of strong elastic scattering of short-wavelength phonons by static and dynamic short-range fluctuations. The condition for localization is considered to be the performance of the Joffe-Regel criterion, when the phonon mean free path becomes of the wavelength order [23]. At temperature increases, the phonon-phonon scattering grouses, and the phonon mean-free path decreases, but cannot become smaller than the phonon wavelength [20, 24]. Further reduction of the phonon mean-free path is not possible and the thermal conductivity (the temperature dependence of which in this temperature range is determined mainly by the reduction of phonon mean-free path) ceases to depend on temperature and approaching to some minimum value. In essence, this is the fundamental in concept of the lower limit of thermal conductivity. The concept of the lower limit of thermal conductivity implies the following [24, 25] $\Lambda_{\min}$ is achieved when the heat transport proceeds as a diffusive exchange of thermal energy between the neighboring quantum mechanical oscillators whose lifetime is assumed to be close to half the period of oscillations. In this case $\Lambda_{\min}$ can be written as [24]:

$$\Lambda_{\min} = \left(\frac{\pi}{6}\right)^{1/3} k_B n^{2/3} \sum_i \upsilon_i \left\{ \left(\frac{T}{\Theta_i}\right)^2 \int_0^{\Theta_i/T} \frac{x^3 e^x}{\left(e^x - 1\right)^2} dx \right\}. \tag{28}$$

The summation is over three (one longitudinal and two transverse) oscillatory modes with the sound velocities υ_i, Θ_i is the Debye cutoff frequency for each polarization in Kelvins ($\Theta_i = \upsilon_i \left(\hbar/k_B\right) \left(6\pi^2 n\right)^{1/3}$), n is the number of phonons per unit volume, and $\mathrm{x} = \hbar\omega/\mathrm{k_B}T$.

In [26, 27] assumed that the combined mean free path of phonons $l_\Sigma(\omega)$ at $T \geq \Theta_D$ is determined by phonon mean free path determined by U-processes ($l_u(\omega)$) and phonon mean free paths for one ($l_I(\omega)$) and two-phonon scattering ($l_{II}(\omega)$). Then, $l_\Sigma(\omega)$ in (27), can be written as [28]:

$$l_\Sigma\left(\omega\right) = \sum_i \left(l_i\left(\omega\right)^{-1}\right)^{-1}. \tag{29}$$

Using [26, 28] the combined phonon mean free path can be presented as [28–30]:

$$l_u\left(\omega\right) = \upsilon / A T \omega^2. \tag{30}$$

$$l_I\left(\omega\right) = \rho \upsilon^5 / B^2 \Lambda_{rot} T \omega^2. \tag{31}$$

$$l_{II}\left(\omega\right) = \pi \rho^2 \upsilon^8 / C^2 k_B C_{rot} T^2 \omega^4. \tag{32}$$

$$A = \left(18\pi^3 \middle/ \sqrt{2}\right) \left(k_B \gamma^2 / m a^2 \omega_D^3\right). \tag{33}$$

where $\gamma = -\left(\partial \ln \Theta_D / \partial \ln V\right)_T$, ρ is the density, V – is the molar volume, B and C are non-central intermolecular interactions constants, Λ_{rot} is the thermal conductivity determined by the molecular rotations, a is the lattice constant, C_{rot} is the heat capacity of orientational subsystem [26, 28].

By substituting (30, 31, 32) in (29) we obtained:

$$l_\Sigma\left(\omega\right) = \left(\frac{AT\omega^2}{\upsilon} + \frac{B^2 \Lambda_{rot} T \omega^2}{\rho \upsilon^5} + \frac{C^2 k_B C_{rot} T^2 \omega^4}{\pi \rho^2 \upsilon^8}\right)^{-1}. \tag{34}$$

In the high temperature limit at $T \geq \Theta_D$ the integral of thermal conductivity (27) is subdivided into two parts describing the contributions to the heat transfer from the low-frequency phonons and high-frequency "diffusive" modes [20, 28]:

$$\Lambda = \Lambda_{ph} + \Lambda_{dif}. \tag{35}$$

where

$$\Lambda_{ph} = \frac{h^2}{2\pi^2 \upsilon^2 k_B T} \int\limits_0^{\omega_D} l_\Sigma(\omega)\omega^4 \frac{\exp\left(\frac{\hbar\omega}{k_B T}\right)}{\left(\exp\left(\frac{\hbar\omega}{k_B T}\right) - 1\right)^2} d\omega. \tag{36}$$

$$\Lambda_{dif} = \frac{\alpha h^2}{2\pi \upsilon k_B T} \int\limits_0^{\omega_D} \omega^3 \frac{\exp\left(\frac{\hbar\omega}{k_B T}\right)}{\left(\exp\left(\frac{\hbar\omega}{k_B T}\right) - 1\right)^2} d\omega. \tag{37}$$

where α is the numerical coefficient of the order of unity determined by the Joffe-Regel criterion [23]. For computation of integrals (36) and (37) we used Simpson's rule for non-elementary integrals and numerical d-Dimensional Simplex method for programming [31]. These computational methods are studied by physics specialties students in the framework of educational course "Numerical Methods".

3. Results and discussion

Using solid C_6H_{12} [32–42], $CHCl_3$ [43–46] and CH_2Cl_2 [44, 45, 47–50] crystals with different type of molecular rotational motion, the thermal conductivity has been simulated (figure 1).

The computer simulation of the isochoric thermal conductivity Λ_v of solid C_6H_{12}, $CHCl_3$ and CH_2Cl_2 using equations (29) – (37) was performed by the parameter fitting method [31], varying the coefficients A, B, C, and α. The necessary data on sound velocity and density in solid C_6H_{12}, $CHCl_3$ and CH_2Cl_2 were taken from refs. [37, 43–45, 50]. The necessary Debye temperatures for $CHCl_3$ and CH_2Cl_2 were estimated from the boundary frequency of translational modes from the Raman and IR absorption data [44, 50].

At present, the thermal conductivity of solid C_6H_{12} has been studied in the temperature interval from $80K$ to the melting point under isochoric and isobaric conditions [14]. The thermal conductivity of solid $CHCl_3$ has been experimentally measured in the temperature range from $80K$ to the melting temperature [51]. To date, the thermal conductivity of solid CH_2Cl_2 has been measured at premelting temperatures [51]. Black squares in figure 1 present the experimental data of the isochoric thermal conductivity of solid C_6H_{12} ($V_{mol} = 95.8 cm^3/mole$), $CHCl_3$ ($V_{mol} = 60.01 cm^3/mole$) and CH_2Cl_2 ($V_{mol} = 47.1 cm^3/mole$) [14, 51]. Figure 1 shows the simulation results for the smoothed values of thermal conductivity Λ_v of solid C_6H_{12} (a), $CHCl_3$ (b) and CH_2Cl_2 (c) and the contributions of phonons (Λ_{ph}) and "diffusive" modes (Λ_{dif}) to the thermal conductivity. As shown in figure 1, the simulation results for thermal conductivity of solid C_6H_{12}, $CHCl_3$ and CH_2Cl_2 (solid line) are in good agreements with experimental data (differences do not exceed 5%).

In solid C_6H_{12} the contributions of Λ_{ph} and Λ_{dif} are approximately the same directly after the β-phase transition (figure 1a). With temperature increases, the contribution of "diffusive" modes decreases and the phonon contribution increases. The best agreement with the experimental data was obtained at α=2.0, A=4.5×$10^{17} s/K$, B=6.9, and C=2.6.

The simulation results for solid $CHCl_3$ are shown in figure 1b (solid line). The same figure shows the contributions (dot-and-dash lines) to the heat transfer from the phonons Λ_{ph} and the high-frequency "diffusive" modes Λ_{dif} (calculated by Eqs. 36, 37). It is seen (figure 1b) that the "diffusive" behavior of the oscillatory modes appears above $100K$. As temperature rises, the amount of heat transferred by the "diffusive" modes increases. The varied parameters

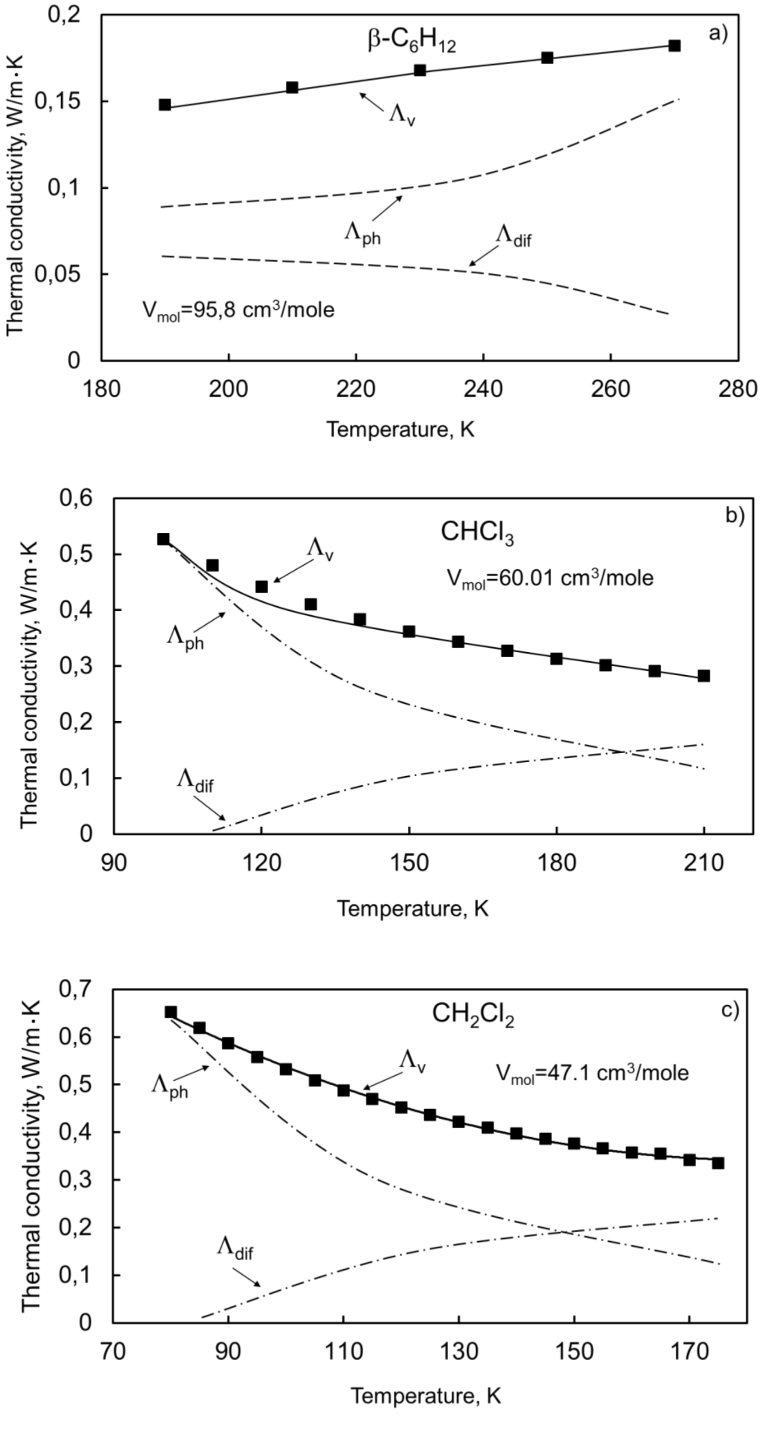

Figure 1. Isochoric thermal conductivity Λ_v of solid C_6H_{12} (a) [14], $CHCl_3$ (b) [51] and CH_2Cl_2 (c) [51] with molar volumes $V_{mol} = 95.8cm^3/mole$, $V_{mol} = 60.01cm^3/mole$, and $V_{mol} = 47.1cm^3/mole$, respectively. The solid line is the fitting curve for isochoric thermal conductivity. Λ_{ph} and Λ_{dif} are contributions of phonons and "diffusive" modes to heat transfer, respectively.

were α and A in orientationally ordered phase of solid $CHCl_3$. The best agreement with the experimental results of solid $CHCl_3$ was achieved with α=2.45 and A=1.2×10$^{16}s/K$. The high-temperature ($T \geq \Theta_D$) behavior of Λ_v in $CHCl_3$ is determined by the balance between phonons and "diffusive" modes contributions to the total heat transfer. The heat transfer by high-frequency "diffusive" modes dominates in $CHCl_3$ at premelting temperatures, and their contribution to thermal conductivity is significant.

The simulation results for isochoric thermal conductivity Λ_v of solid CH_2Cl_2 are shown in figure 1c (solid line). This figure shows the contributions (dot-and-dash lines) to the heat transfer from the phonons Λ_{ph} and the "diffusive" modes Λ_{dif}. The fitted values of varying parameters are α=1.7 and A=1.33×10$^{16}s/K$. It is seen (figure 1c) that in solid CH_2Cl_2 the "diffusive" behavior of the oscillatory modes starts above $90K$. As temperature rises the amount of heat transferred by the "diffusive" modes increases. Above $150K$ most of the heat is transported by "diffusive" modes.

4. Conclusion

This article is devoted to the implementation of scientific achievements into the educational process of physics specialties students. In this work we present the results of molecular crystals thermal conductivity simulation under quantum-mechanical approach. This approach is very useful for students, because it demonstrates the dualism of the nature of heat transfer processes in dielectric crystals. The basic provisions of quantum-mechanical approach are studied by students in the framework of university study course "Solid State Physics" and are based on classical models of Einstein and Debye. In the framework of this approach the isochoric thermal conductivity of solid C_6H_{12}, $CHCl_3$ and CH_2Cl_2 have been simulated under assumption that in molecular crystals heat is transferred due to the phonon-phonon interaction and thermal diffusion between the thermally activated neighboring quantum mechanical oscillators. In this case, heat is transferred by low-frequency phonons and above the phonon mobility edge ω_0 by "diffusive" modes. The results obtained in this investigation demonstrate that the quantum-mechanical approach for thermal conductivity of molecular crystals is adequately describe the experimental temperature dependencies of thermal conductivity and can be used for simulation of heat transfer processes features in molecular crystals with different type of molecular orientational motion. This study showed the dual mechanism of heat transfer processes in molecular crystals at temperature of the order of the Debye temperature and above. The presented quantum-mechanical approach can be useful for implementation in the educational process in the study course "Solid State Physics", in particular for understanding the features of heat transfer in the high-temperature range of dielectric crystals existence.

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Experience in the development and implementation of a system of visualized teaching cases in Physics using a digital computer measuring system *Einstein*

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Experience in the development and implementation of a system of visualized teaching cases in Physics using a digital computer measuring system *Einstein*

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Abstract. Time has come to form a new education system. This is confirmed by the UNESCO initiative on the future of education for 2050 and thereafter and provides an opportunity to understand how education can shape the future of humanity and the planet. Today, the development of ICT, artificial intelligence, digital platforms and information growth are agents of change in the educational process. The amount of information in the world doubles every day; information-oriented society (a community connected to each other and the world through information and technology) is being formed. Open information systems, global educational networks, interacting digital resources, developing digital educational and information resources provide an opportunity to improve the quality of education. In view of this, special information educational resources are developed in accordance with the trends of science, regional context, individual characteristics and needs of students. In recent years, STEM education has been actively developing both in the world and in Ukraine. This contributes to students' involvement into STEM disciplines, and young people's choosing engineering professions. This article substantiates the feasibility of developing a system of visualized teaching cases in Physics. A classification of educational cases is proposed. The paper describes the experience of development and introduction of visualized cases using a combination of Google-services and digital computer measuring system *Einstein* in the process of teaching Physics as a STEM-discipline. The method of organization of classes with the help of digital computer measuring complex *Einstein* in the context of situational teaching of Physics is suggested. The article also presents the analysis of the results of implementation of the system of visualized Physics teaching cases into educational process on the basis of Physics and Educational Technologies Laboratory of Kherson State University.

1. Introduction

Around the world, education is a top global priority, a major driver of human empowerment [1]. Realizing the importance and the need for education reform, the New Ukrainian School Concept draws attention to 10 key competencies of a modern person, including mathematical competence, basic competencies in the natural sciences and technology (scientific understanding of nature and modern technology, the ability to apply the scientific method, observe, analyze, formulate hypotheses, collect data, conduct experiments and analyze monitoring results), information and digital competence (using ICT to create, search and share information); the ability to learn over the course of life and much more. Also, attention is drawn to the need for cross-cutting use of information and communication technology (ICT) in the educational process [2]. Today's future of countries provides the most popular to date development of research capacity and strengthening of natural science engineering education and open learning, including the use of open educational resources, free and open source software, open learning platform [3].

The trends that are actively expanding and carrying out this process, those are.

(i) Adaptive learning is moving to the next level, which considers the e-learning market.
(ii) Microlearning. This is a great method of implementing learning in small pieces that are object-oriented and can be easily and quickly deployed within a group.
(iii) The artificial intelligence and learner assistance. Artificial intelligence allows for personalized learning.
(iv) Gasification and game-based teaching. Games that are well designed, developed, and address students' needs to effectively engage them.
(v) Additional reality AR / virtual reality VR / mixed reality MR. The augmented reality can expand the content available with interesting overlays of graphics and images that can jump out and excite students.
(vi) Video-based learning.
(vii) Social learning. It expects cooperation between people in the workplace through various modes [4].

Introduction of the case method in the educational process gives an opportunity to realize certain trends and tendencies of education and contributes to the formation of certain competencies defined above. The case method as a teaching tool can help attract students to research in any discipline, especially physics, using the interdisciplinary connections between science, math, and computer science through a virtual physical case-environment.

2. Related works

The analysis of Internet resources and scientific publications makes it possible to state that:

(i) Today STEM-education is actively developing in Ukraine and in the world. It is confirmed by a large number of educational resources, platforms and organizations at different levels (STEM.org, LaSTEM (USA), STEM learning (United Kingdom), Inclusive Stem (India), NUSH Institute for the Modernization of Education Content (Ukraine), etc.) [5,6]. Most of these educational services are built with an orientation on life situations and the solution of real (lifestyle) problems, the use of active and interactive teaching methods corresponding to the content of the case technology, and focused on mastering technical and related scientific competencies;
(ii) use of personality-oriented active methods in physics teaching is associated with the needs to improve science education quality, including physics [5–9];
(iii) use of various means of virtual learning is associated with a number of factors that contribute to improving of the education quality, in particular: accessibility, flexibility, the ability to take into account the requirements and characteristics of the student and teacher, expanding the scope of educational services, increasing the motivation level [10];
(iv) case-technologies in various disciplines are being actively developed and introduced around the world; case-technologies are being introduced by special organizations, centers ("Case Method Teaching" (Stanford) [11], NCCSTS [12], WACRA- World Association for Case Research and Application (Czech Republic, Spain, England) [13], Center for Innovation in Teaching and Learning (CITL) (Columbia) [14], Center for Support and Innovation in Teaching (CTSI) (Harvard), etc.), and scientists, teachers, educational institutions at various levels [15–17];

(v) case method instruction as the "art of uncertainty management" - a process in which the teacher serves as planner, host, moderator, "devil's advocate, and judge" - in the search for solutions to real world problems [16];

(vi) case method of training is based on the use of real situations (cases). This method helps to improve skills: identifying and solving problems, working with information, decision making, and teamwork skills. The case method is not universal, but it can easily be combined with other training methods. Its main advantage is that students acquire different skills in the work, tasks are implemented on real events, so they allow to use theoretical knowledge in practice [18];

(vii) scientists determines different classifications (typologies) of learning cases, summarized on figure 1). Among the methods of working with a case, the method of situational analysis, the method of incidents, the analysis method, staging, game design, the discussion method are distinguished [19];

(viii) didactic requirements to the case's content: the case must be written in interesting, simple and understandable language; be characterized by "drama" and complexity. It should clearly define the "core" of the problem, show both positive and negative examples; meet the needs of the selected students, contain necessary and sufficient information. The text of the case must not offer any solutions to the problem [18].

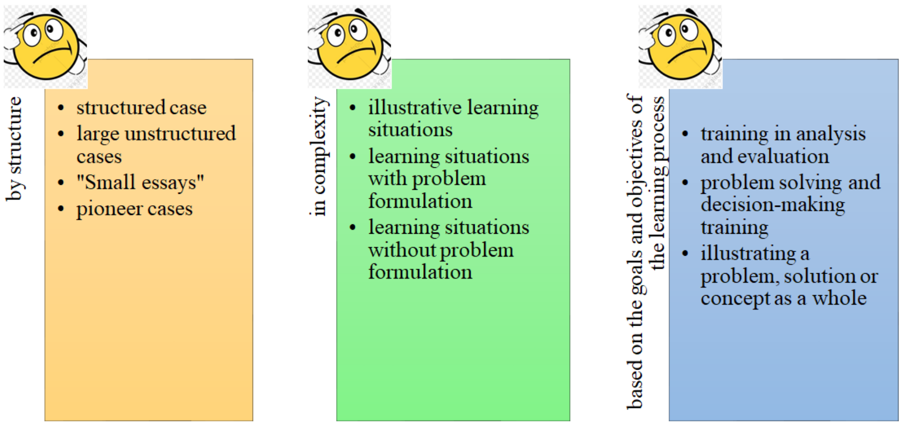


Figure 1. Learning cases classifications.

The results of the expediency of using cases, their implementation using a virtual environment created with the help of Google services were presented in [5], in particular, it was found that this form of presentation of case studies not only helps the teacher in organizing the lesson, control, but also increases students' interest in the study of physics.

The increase of information makes it difficult to collect and analyze, so visualization is especially important. It reduces the time to perceive the information. Visualization is "the process of presenting data in the form of an image for maximum ease of understanding any conceivable object, subject, process, etc." [18].

Realizing the importance of visualization of physical knowledge, possibilities of case studies, virtual learning environments, and peculiarities of physics as an experimental science, we decided to combine the implementation of virtual cases with a real physical experiment to simultaneous visualization of its results in a case and to introduce new concepts.

In our study, "visualized learning case" is a computerized case, which allows combining a virtual experiment with real performance of experimental tasks. The use of such tasks allows transferring information about the studied objects, processes and phenomena directly to a personal computer; to process the obtained information in real time; to provide the teacher with information about the possibilities of learning, the specific features of students' mental activity. Didactically, tested use of visual images in teaching physics can transform visualization from an auxiliary, illustrative tool into a leading, productive methodological tool. Teacher can choose the case's type and implementation using the *Einstein* World app.

It should be recognized that visualization of learning material should not entertain, but attract attention and motivate. In this case, it will be effective.

3. Features of Using the *Einstein* Platform in Situational Physics Instruction

An analysis of the possibilities of using the *Einstein* learning platform (which combines software and a set of sensors for physics, chemistry, and biology) in situational physics teaching made it possible to determine the next things:

1) The *Einstein* kit includes:
   - external sensors: photo-turn (sensor measures the time it takes for an object to pass under the sensor arch), current sensor, temperature sensor, thermocouple sensor, force sensor, noise sensor, voltage sensor, microphone, magnetic induction sensor, distance sensor;
   - built-in analog-digital converter *Einstein* LabMate + (heart rate monitor, humidity, light, UV radiation, pressure, thermometer). With the help of the complex, it is possible to conduct a variety of experiments, turning an ordinary computer, tablet or smartphone into a full-fledged digital science laboratory.
2) The software for the sensor set can be download on both Android and IOS:
   - *MiLAB* is a mobile application that allows receiving and analyzing data from *Einstein* sensors in real time. It can display data in graphs (up to 7 graphs at once), and allows monitoring several different related indicators to study dependencies and rules;
   - "*Einstein* World" (access `http://activitystore.einsteinworld.com/`) - has a set of ready-to-use interactive exercises using sensors (it is necessary to register on the site or log in via your Facebook or Google account). The *Einstein* World interface (figure 2).

Einstein World easy-to-use interface allows sorting the problems by topic (physics, chemistry, biology, environment), by language, by age, by sensors to be used. The disadvantage of the *Einstein* World program is there are very few tasks in Ukrainian. But its value is the ability to develop own interactive tasks (case tasks).

The teacher who creates the case-study tasks has the ability to add videos, pictures, music, diagrams, and graphs and immediately add questions to summarize and test the gained knowledge (figure 3). This software can be used to design virtual cases using a set of sensors. It extends cases' using in physics study and visualizes them.

So, we developed a number of visualized physics cases for 9th grade students of general secondary education institutions in different topics and placed them on the website of the virtual educational environment "Educational Platform" as links [5].

It makes easy to organize group and individual work with cases in class. The model of the educational process organization using the virtual case study environment and the *Einstein* World program is shown in figure 4 and consists of the following components: teacher, students, virtual educational environment "Educational platform" and *Einstein* World application.

The result of our work was the development of: 1) the algorithm of the teacher's activity (table 1); 2) step-by-step instructions for the student at working with a visualized case (table 2); 3) methodological recommendations for organizing work with a case.

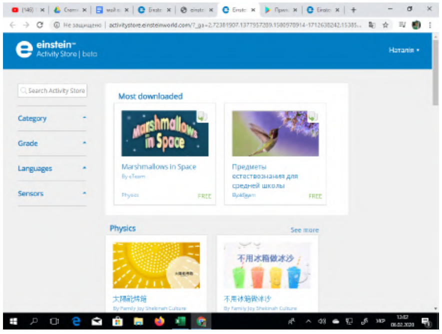


Figure 2. *Einstein* World interface.

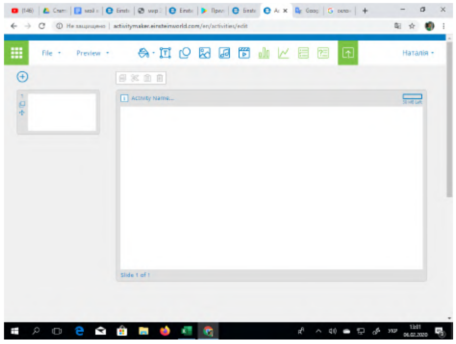


Figure 3. The window for visualized cases in *Einstein* World development.

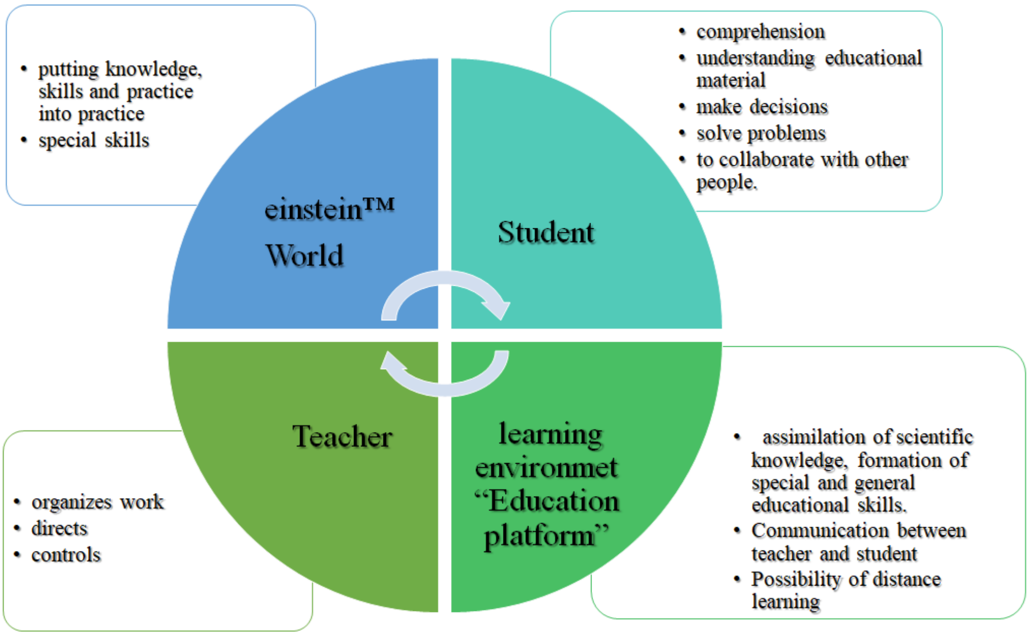


Figure 4. Educational process organization model.

3.1. The example of using a visualized "Harry Potter" case for the 9th graders in geometric optics study

The purpose of the visualized case is to deepen student' knowledge in geometrical optics, test the knowledge of the laws of geometrical optics (rectilinear diffusion of light, reflection and refraction of light); develop students' cognitive interest, motivational sphere, and improve such basic competencies as critical thinking, technological and information literacy, and cooperation skills.

The task of the visualized case "Harry Potter":

Students should watch a fragment of the movie, identify three physical situations, independently formulate problems for them, and test the laws of geometrical optics in practice:

1) Mrs. Norris saw Basilisk in the reflection of water (investigate the course of the rays, simulate the situation using a distance sensor to investigate the laws of refraction and reflection).

2) Colin Cravey saw Basilisk through a camera lens (using a camera lens to investigate the

Table 1. Teacher activity algorithm and student activity during the visualized case study.

Stage of work activity	Teacher activity	Student activity
1	Providing students with an link to prepare for the assignment, explaining how to work with the visualized case and a set of sensors.	Install the *Einstein* world app on the computer, tablet, or phone
2	Performing organizational, moderating, corrective, supervisory functions. Helping students with the use of sensors (if need)	Download the case from the virtual educational platform "Education Platform" or the Einstein™ World search panel
3	(the same)	Individual or group self-completion of the case. (Self-formulation of the purpose of the research, the tasks to be achieved)
4	Controlling the process of discussing the results	Defending of the results of one's own research

course of rays during light refraction, determine the index of refraction in various media using a distance sensor).

3) Hermione saw Basilisk in a mirror reflection (simulate this situation using the distance sensor from the set, check the law of light refraction).

3.2. Methodological recommendations for learning case usage in the educational process

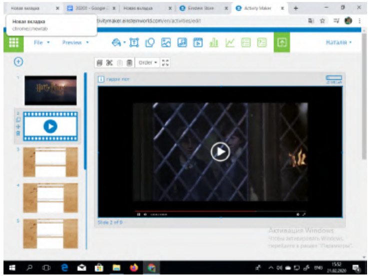
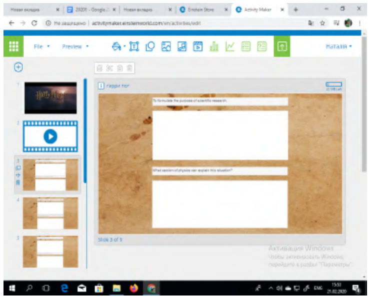
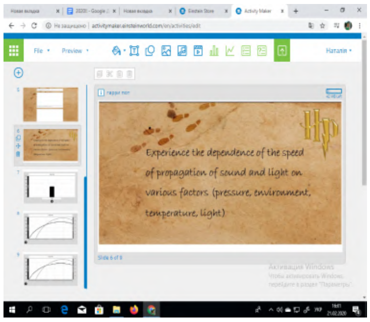
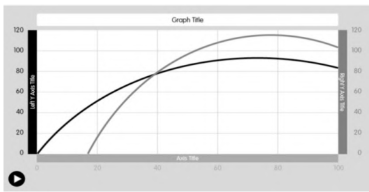
First, it is needed to determine the methodological goal of situational learning in a particular lesson. The choice of lesson's type, the form of the learning organization and the methodology of its carrying out should be coordinated with the methodological goal. There are the variants of the organization of work with a visualized learning case.

1) The case as an experimental task may be used in its entirety in class or offered as homework. In this case, it is reasonable to divide it into three separate tasks (see above). Since the performance of the case involves the complex application of already acquired knowledge, the type of lesson for the presentation of the completed tasks should be a "lesson of knowledge generalization and systematization".

2) A possible variant of work with a case is the execution of an educational project based on the formulated case assignments. In this case, the work should be divided into two stages: a) homework (preparation and implementation of the project); b) work in class (presentation of the results of the project task).

3) The proposed case can be used as a laboratory work. Type of lesson is a "lesson of practical skills formation". The advantage of the case-based laboratory work is its exploratory nature, the connection with real-life situations. It contributes to the cognitive interest development. It is advisable to use the case when students have a specific knowledge base on the topic. It is not recommended to use it to study a new topic.

Table 2. Step-by-step instructions of visualized Harry Potter learning case.

Explanation	Visualized case screen
Step 1: Watch an episode of "Harry Potter and the Chamber of Secrets"	
Step 2: Analyze the video fragment: - formulate the purpose of a possible physics study, - formulate a question for the video from the point of view of physics, - formulate a hypothesis about the possible physical research in the fragment of the video.	
Step 3: Compare your personal hypothesis with the proposed hypothesis.	
Discuss the results of the research in a mini-group, prepare a report, discuss the results of the research in class.	

4. A study of improvements in students' motivation during situational learning using the *Einstein* set

In order to investigate the appropriateness of using this type of lessons, the components of motivational structure related to the level of pretensions were investigated by questionnaires [20]. Students of the 9th grade of Kherson Academic Lyceum of Kherson State University took part in the study:

-group A - the control group, got written or verbal tasks of the traditional type (30 students),

-group B - experimental, worked with visualized cases (30 students)

For the study, three components of the motivational sphere were identified. These are the three main groups of motives, each of which can be investigated and analyzed. The list of groups of motives is shown in figure 5.

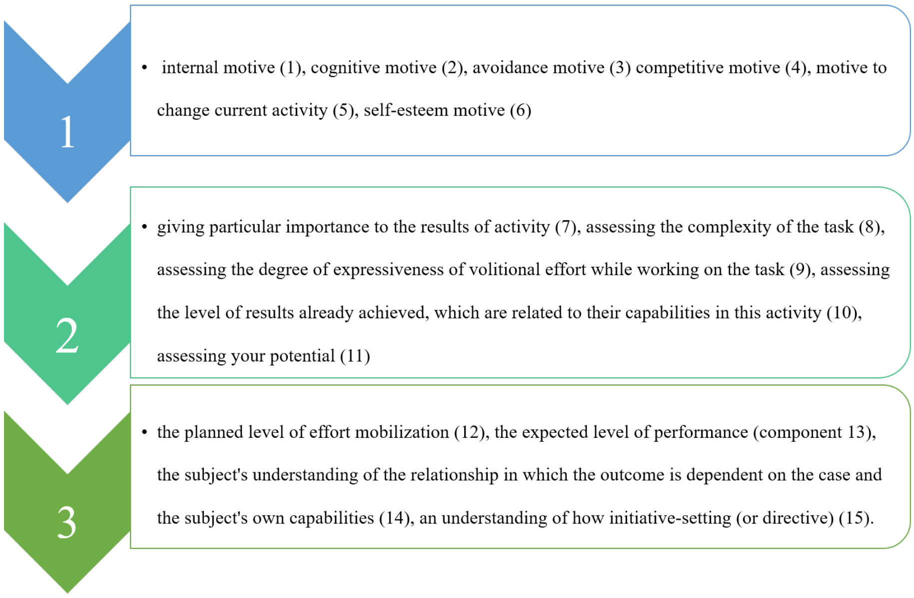


Figure 5. Groups of studied motives.

The presented elements are potential components of real individual motivational structures arising at task performance [20]. The questionnaire used in the research process contained the questions below. According to the components of each group, the student had to assess to what extent he or she agreed or disagreed with the statement and give a score (-3;-2; -1; 0; +1; +2; +3). Then the data were processed according to the rule of direct and reverse transfer of points given in the instructions to the questionnaire.(the maximum number of points when translating students' answers 7)

The average results of students' survey after completing the three case-tasks are shown in figure 6.

Comparison of the results of the questionnaire presented in figure 7 showed the presence of positive improvements in the levels of motivational sphere of students. Compared to the control group A, students in group B had an average increase of 2.1% in the indicators of intrinsic and cognitive motives at the time of the visualized learning cases. On the contrary, the tendency to discontinue the work performed decreased, which indicates an increased interest in the performance of situational tasks.

During research of the second set of motives, it has been established that such elements as "evaluation of degree of volitional efforts expression" (component 9), "evaluation of level of already achieved results which are connected with their opportunities in this activity"

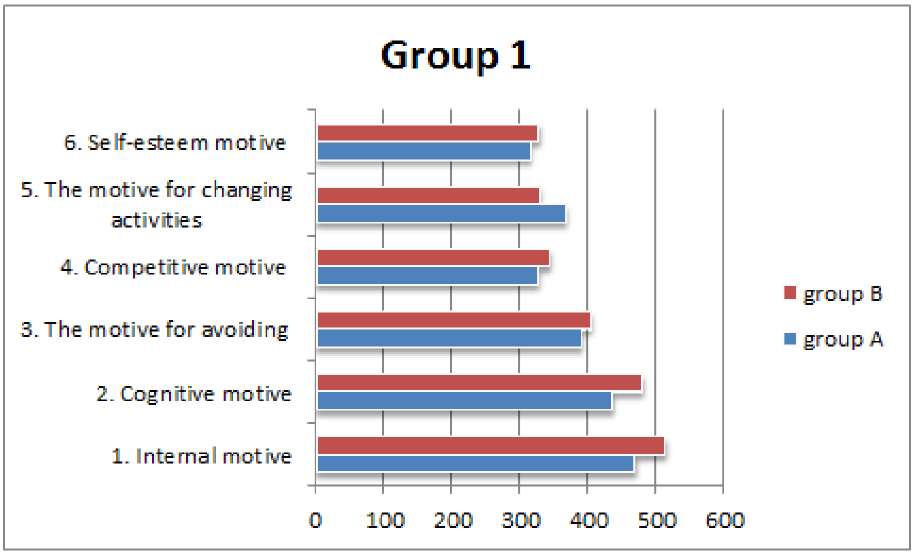


Figure 6. Distribution of students in the first group of motives at the beginning and at the end of the pedagogical experiment.

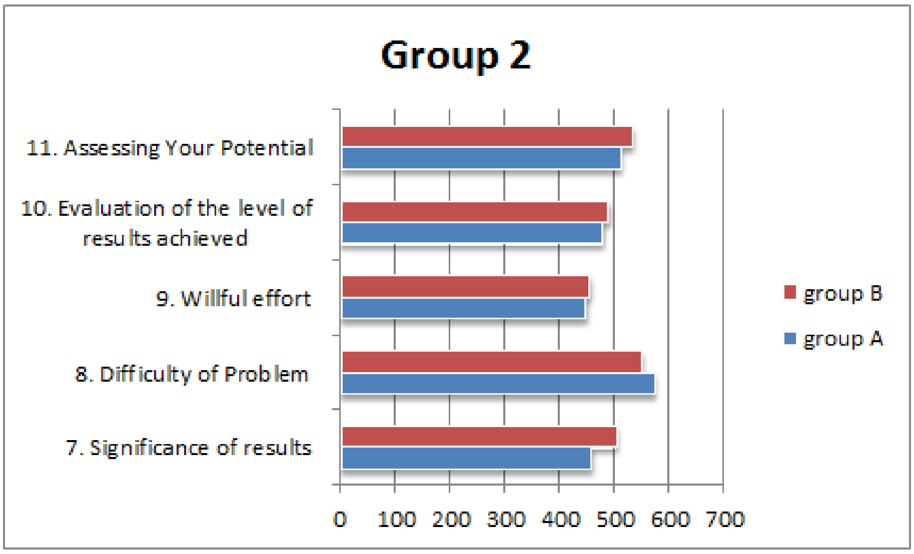


Figure 7. The distribution of students by levels of the second set of motives at the beginning and at the end of the pedagogical experiment.

(component 10), "evaluation of potential" (component 11) do not differ significantly in importance in two groups.

The analysis of the results of the questionnaire on the third group of motives showed that in groups A and B the students' distribution on the element "understanding how much the task setting is initiative" (or "directive") is significantly different. It indicates a positive trend of students' motivation to study physics with the help of visualized cases (figure 8). The survey's results showed there were positive improvements in the levels of the components of the motivational sphere related to the students' attraction level. The results of the students' survey were statistically substantiated using the T-Wilcoxon statistical criterion ($p<0.05$).

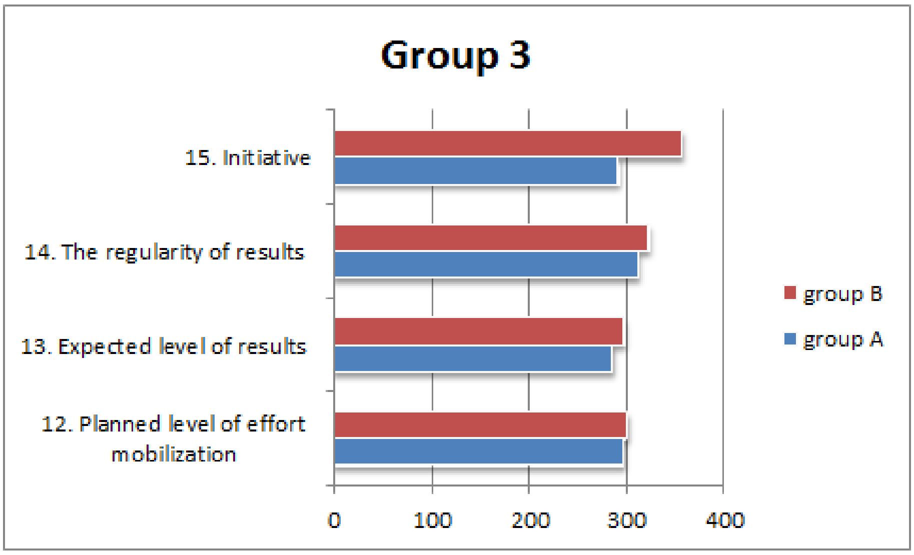


Figure 8. Distribution of students by levels of the third group of motives at the beginning and at the end of the pedagogical experiment.

5. Conclusions and perspectives

In the context of active transformation of Ukrainian education, special attention should be given to innovative teaching methods, technologies and techniques that will help to embody the ideas of open education, STEM-education. Case-method is a learning technology based on the solution of economic, social and business situations. The use of visualized learning cases in physics allows teachers, combining experiments, interactive multimedia and convenient analysis software on any tablet or computer, to inspire students, giving them the opportunity to immerse themselves in the exploration of physical processes and phenomena. The combination of virtual and real experiments allows immediately realize the knowledge. Visualization of tasks increases students' interest in physics studying and encourages them to further work. Studies of the motivational sphere have shown the expediency and necessity of using visualized learning cases in teaching physics.

The prospect of further research is to develop a system of visualized learning cases in other sections of the school physics course and methodological recommendations for their use.

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Using smartphone sensors for teaching mechanical oscillations

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Using smartphone sensors for teaching mechanical oscillations

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Abstract. As a complement to the traditional elements of the physics laboratory, alternative strategies are sought that allow the experimentation of mechanical oscillations and improve the understanding of these phenomena by university students. Smartphones have very high quality built-in sensors, which in the particular case of the gyroscope allows to carry out oscillator experiments with excellent results. Two experiments that were implemented with the gyroscope integrated into a smartphone are shown. Appropriate setups are suggested to make these experiments.

1. Introduction

In recent years, the internal sensors of smartphones have been used to perform mechanical oscillation experiments in education [1-4]. In other cases, phone sensors have also been used as sound transducers in medical applications [5]. MEMS (Micro-Electromechanical Systems) sensors are used in multiple industries, such as automotive, aerospace, medicine, etc. [6-10]. A sensor measures the variable of interest at regular intervals, the number of measurements per second made by the sensor is called the sampling rate. When the measured variable changes very quickly over time it is necessary to adjust the sampling rate so that the data taken by the sensor are representative of the temporal variation of the studied variable. Both the accelerometer and the gyroscope of the smartphone are sensors that can have sampling frequencies of more than 300 HZ. For this reason, these sensors are an excellent tool for conducting experiments with mechanical oscillators. Among the many experiments with mechanical oscillators, we can

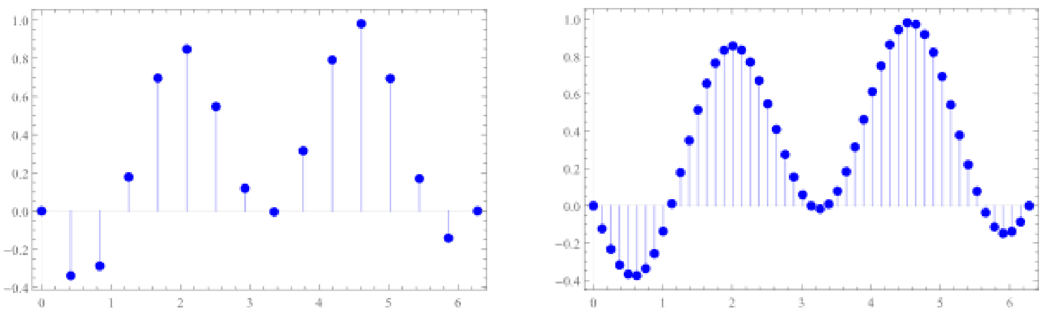

Figure 1. Evolution of the same variable measured with two different sampling frequencies.

refer to the physical pendulum and the damped oscillator. To perform these experiments there is a mobile application called Physics Toolbox Suite which allows you to select the sensor of the smartphone you want to use, adjust the sampling frequency, and generate a CSV (Comma-Separated Values) data file.

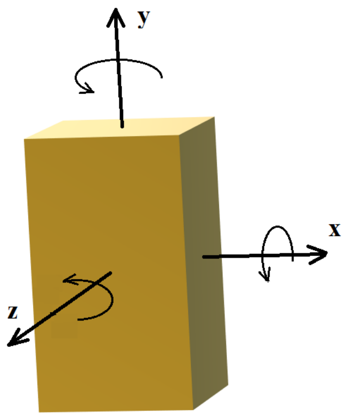

Figure 2. The axes of the smartphone.

Figure 2 represents the axes of a smartphone. The x-axis is directed in the horizontal direction and together with the y-axis represents the plane where the smartphone display is located. The z-axis is in the normal direction to display. The smartphone has several sensors (accelerometer, gyroscope, magnetometer, etc.), each of which can measure the variable of interest on each of these axes.

2. Gyroscope operation

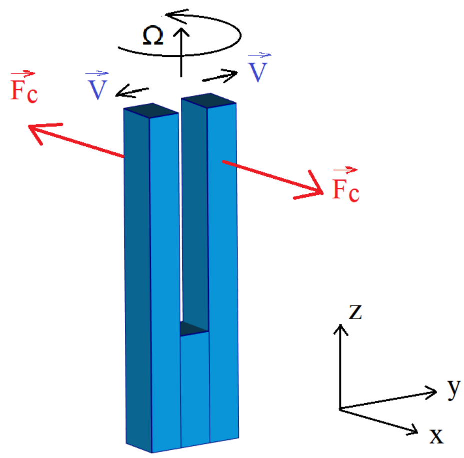

Figure 3. Schematic representation of the gyroscope.

The smartphones have a built-in gyroscope to sense their angular movement around the axes. The gyroscope that is integrated into the smartphone is a MEMS device that can be represented in the form of a tuning fork. For didactic purposes, its operation can be explained as follows: when the gyroscope is activated the arms of the fork oscillate according to $y = y_{max} \cos \omega_D t$ in counterphase. The angular frequency ω_D (drive frequency) is achieved by a piezoelectric element connected to an alternating voltage

$$V_D = V_{max} \cos \omega_D t \tag{1}$$

When the system rotates around the z-axis with an angular velocity Ω, on the fork arms the Coriolis force appears perpendicular to drive mode in the x-direction.

$$\vec{F}_C = -2m\vec{\Omega} \times \vec{v}, \tag{2}$$

where m is the mass of the arm, $\vec{v}$ is velocity in the y-direction. The movement of the tuning fork arms in the direction of the sensor mode can be modeled with the following differential equation

$$m\ddot{x} + c\dot{x} + kx = -2m\Omega v, \tag{3}$$

where c is the damping constant, k is the elasticity constant. Then, when $\omega_D \gg \Omega$, the X position can be calculated as $X \approx \Omega$ and can be measured by capacitive effects, when the sensor arm is taken as a part of a capacitor whose voltage is the measurable variable. Therefore, the measured voltage will be proportional to the angular velocity of rotation around the z-axis.

3. Experiments with mechanical oscillators

3.1. Physical pendulum

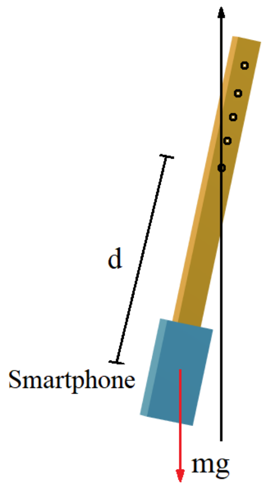

Figure 4. Physical pendulum.

To set up a physical pendulum some holes are drilled in a plastic or wooden ruler, then a smartphone is fixed at one end. This pendulum is fixed from support with a tip through one of the holes in the ruler. It oscillates while taking the data with the smartphone's gyroscope. A CSV file must be generated; later the data will be analyzed on a computer. The d-value is the distance from the point of support to the center of mass of the smartphone. For each hole position, must be taken angular velocity values and created a CSV data file.

3.2. Damped oscillator

The following settings can be made to create a damped mechanical oscillator; the smartphone is held to two upper extreme points with two strings, as seen in figure 5. The strings are fixed from a 0-stationary position so that the smartphone can oscillate in the direction of the z-axis. This pendulum swings with the application that activates the gyroscope and generates a CSV data file.

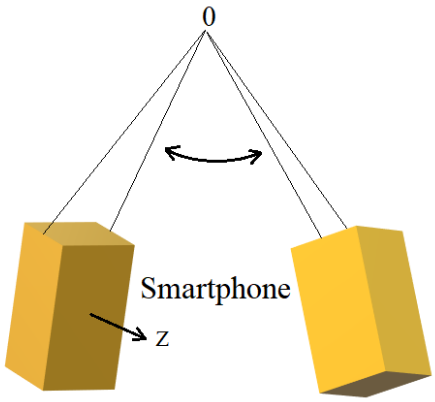

Figure 5. Damped oscillator.

4. Results

The figures presented below were obtained from data taken with a BOSCH BMI120 gyroscope integrated into a smartphone. The selected sample rate was 394 Hz. Figure 6 shows the evolution of the angular velocity of the physical pendulum for one of the d-values. As can see, the measurement time is more than 60 seconds, during which more than 23000 measurements were obtained.

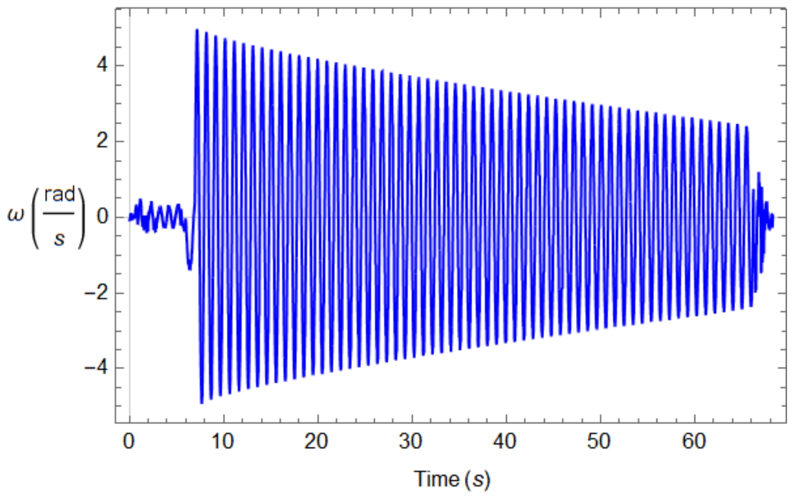

Figure 6. Data representation of the angular velocity from the physical pendulum.

Any periodic signal $x[n]$ can be represented by the sum of the Fourier series. With proper analysis, it is possible to obtain a Fourier representation for signals of finite duration. This representation is known as DFT (Discrete Fourier Transform). The DFT can be obtained as

$$X[k] = \sum_{n=0}^{N-1} x[n] e^{-i\frac{2\pi kn}{N}} \tag{4}$$

When the number of data N is very large as in this case, the DFT is very difficult to calculate even with computer programs. A new method is required to simplify the calculation of the

Fourier transform. This mechanism is the FFT (Fast Fourier Transform) which enormously reduces computing costs. Figure 7 shows the normalized FFT of the data in Figure 6 evaluated with Python between 10 and 60 seconds; it is observed that the frequency of the movement is approximately 1.03 Hz. This experiment with the physical pendulum must be repeated for each d-value. Once the oscillation period T for each d-position has been established, the following potential relationship can be calculated

$$T = Ad^B, \tag{5}$$

where A and B are constants.

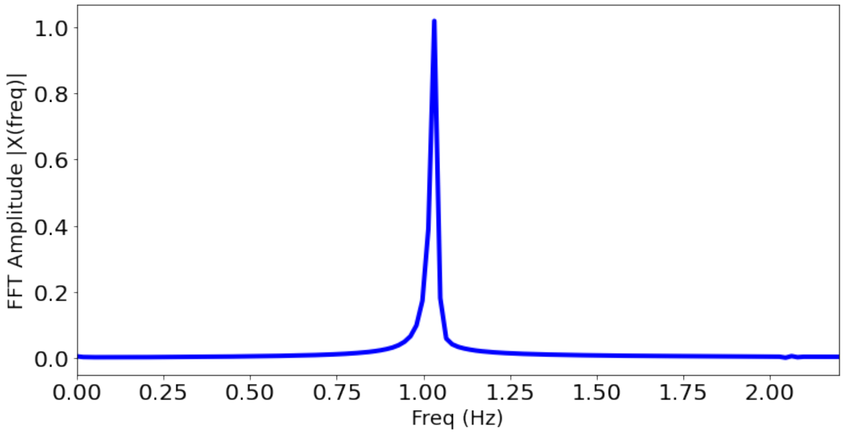

Figure 7. Normalized FFT of the angular velocity from the physical pendulum.

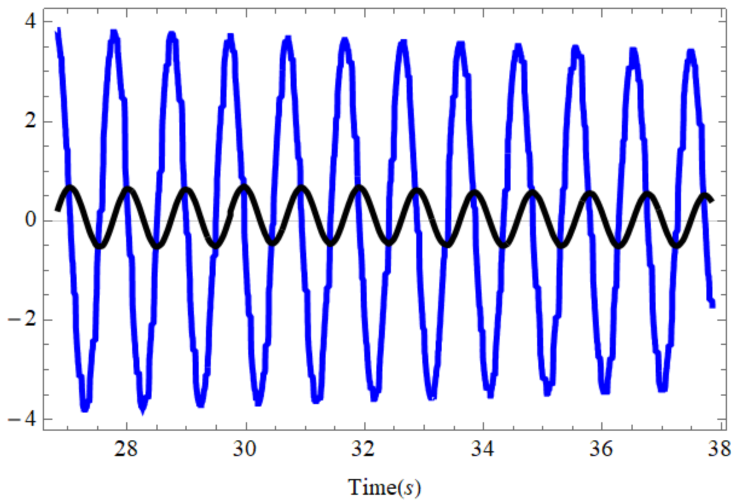

Figure 8. Angle and angular velocity of the physical pendulum.

A small part from the sensor data was taken to compute the pendulum's angular position as a function of time. As we know the angular velocity ω_i at time t_i and initial angular position θ_0, we can calculate angular position θ_n, with the following equation

$$\theta_n \cong \sum_{i=1}^{n} \omega_i(t_i - t_{i-1}) + \theta_0 \tag{6}$$

Figure 8 shows a time interval of approximately 27.5 s to 38 s of the same data as figure 6. The blue line shows the angular velocity from sensor data, and the black line corresponds to the angle evolution, obtained by the procedure indicated in equation (6). The maximum value of the angle $\theta_{max} \cong 0.5\ rad$. As expected, when the angular velocity is maximum the value of the angular position is zero.

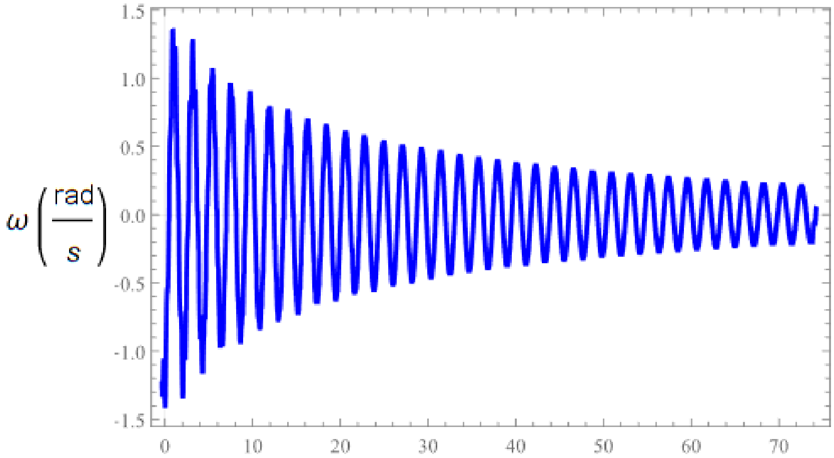

Figure 9. Angular velocity of the damped oscillator.

Figure 9 shows the angular velocity of the damped oscillator over 70 seconds. The envelope function of the angular velocity ω evolves in a decreasing exponential way, as follows

$$\omega = \omega_0\, e^{-\gamma t}, \tag{7}$$

where ω_0 is the initial velocity and γ is the damping constant. The value of the damping constant γ can be obtained in two ways:

(i) The derivative of (7) is obtained

$$\frac{d\omega}{dt} = -\gamma\, \omega \tag{8}$$

Then

$$\frac{\Delta\omega}{\omega_0} = \frac{\omega - \omega_0}{\omega_0} \cong -\gamma\, T, \tag{9}$$

where T is the oscillation period.
The values of two consecutive peaks of the angular velocity are taken, hence the period may be measured. Then the value of γ is calculated using the expression (9). This procedure can be repeated sometimes and from there obtain an average value with its uncertainty.

(ii) Finally, determine two peak velocity values, first $\omega_1 = \omega_0$ and another close to half of the first measured value $\omega_2 = \omega_0/2$, and time interval t between them. The value of γ may be calculated from (7), as follows

$$\gamma = \frac{1}{t}\, ln\frac{\omega_1}{\omega_2} = \frac{1}{t}\, ln2 \tag{10}$$

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5. Conclusions

Compared with traditional classroom experiments, the smartphone sensors used on this occasion have high precision and robustness, and the number of data acquired in these experiments is quite large; so, this gives great reliability to the results. There are many alternatives for the use of these tools in university teaching, which should continue to be explored.

6. Acknowledgments

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PAPER • OPEN ACCESS

Relationship between achievement in physics and mathematics and family functioning

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Relationship between achievement in physics and mathematics and family functioning

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Abstract. The development of pedagogical-psychological theories causes an increase in the number of examined factors (cognitive and non-cognitive). One of the non-cognitive factors is the family environment, so the paper deals with determining the connection between success in physics and mathematics and family functioning. In the research, 80 seventh and eighth-grade elementary school students participated. The constructed questionnaire included eight dimensions of family functioning: cohesion, flexibility, disunity, networking, chaos, rigidity, family communication, and family satisfaction. Results showed that students whose parents are married achieve significantly higher scores on all four mentioned scales. The children whose parents are divorced achieved the lowest marks. Also, the dimensions of communication and family satisfaction are rate as good. The chaotic component was influenced by parents‘ level of education, where the highest value was expressed by students whose parents are at the primary school level. This component proved to be important for students' achievements in mathematics. Achievements in physics were influenced by the level of cohesion, whose increase also caused a higher student achievement. Family environment is an important factor determining students' development, functioning, and school success, so it is important to monitor its impact and train teachers to work with students from dysfunctional families.

1. Introduction

The development of pedagogical-psychological theories causes an increase in the number of examined factors (cognitive and non-cognitive). The aim was to determine and understand student achievement as completely as possible. Increasingly present cognitive factors that appear in research are related to the development of executive functions and working memory capacity [1] i.e., the cognitive load of students and mental effort as its measurable part [2–4]. The most important non-cognitive factors are personality traits, motivation, and family environment [5,6]. The family environment stands out because it affects the development and formation of students‘ personality traits and their motivation to learn. Therefore, this paper examines the connection between family functioning and student achievement in physics and mathematics. Within the family functioning, the most important factors are the parent's education, the number and structure of the family, and the marital status of the parents [7,8]. The family atmosphere can have a stimulating or limiting effect on students' school achievement. The result of the family environment is reflected in its contribution to the formation of the child's personal, properly directed characteristics and the versatile development of their abilities. The same functionality of the family was reflected in commitment, trust, and solidarity. Family cohesiveness represents togetherness and emotional connection between family members. It is measured by examining emotional connections, borders, coalitions, how decisions were made, interests, reactions [9]. Medium levels of cohesion are considered healthy, which indicates the optimal level of connection and separation in family relationships. Families who have this level of cohesion spend time together, make important family decisions together, are strongly emotionally connected and close. Families with a low level of cohesion are too focused on themselves, their own lives and friends, and spend little time socializing with other family members [10,11]. Family decisions are usually made by one dominant member-leader. On the other side of the cohesion, the spectrum is too networked families, with extreme closeness and loyalty. Members of these families are very dependent on each other, there is no private space, there is a problem of separation, and family boundaries are too tight and do not miss even friends [12]. Flexibility or adaptability is a model dimension that refers to how the family finds a balance between stability and change. It encompasses the relationship between roles, negotiation, and leadership. According to Olson [12], flexibility is manifested through family members' assertiveness in mutual relations, control, disciplinary measures, and the enforcement of the rules. Unbalanced family relationships often show too much rigidity and control in relationships, where there is no negotiation, and the leader makes the decision. Family relationships characterized by chaos have variable leadership, and family decisions are made impulsively and recklessly [13–15]. The rules change from situation to situation. Therefore, even in this dimension, "healthy" families are those that are flexible enough to adapt their functioning to changed requirements, the crisis or change, but still assertive enough to make family decisions assertively and responsibly [16]. The third dimension of Olson's model is communication, and it is considered the third dimension. This third dimension influences the function of the previous two dimensions. Healthy families have good communication, while dysfunctional communication is weak and chaotic. This dimension is measurable through the skills of listening, speaking, clarity, concentration on the topic, openness, appreciation, and respect between members [17]. Family functioning according to the presented Olson model is assessed using the FACES IV questionnaire [18]. FACES IV is the latest version of the Family Self-Description Questionnaire, designed to measure cohesiveness and family adaptability. This questionnaire considers both the spectra of balanced family functioning, which characterizes functional families, and unbalanced, which characterizes dysfunctional families. The balanced scales of the FACES IV questionnaire are balanced cohesiveness and balanced adaptability or flexibility [17]. These scales are linear, so the higher score and the more positive the result. Unbalanced questionnaire scales are networking, disunity, chaos, and rigidity. These four scales make up one of the four extremes of the dimensions of cohesiveness and adaptability — the higher score on these scales, the more dysfunctional the family. Therefore, the FACES IV questionnaire distinguishes six types of families: balanced type, rigidly-connected type, transitional, flexible-unbalanced, chaotically-disunited, and unbalanced family type [17]. Given the wide acceptance of the Circumplex Model of Family Functioning [19] and the importance and accuracy of the FACES IV questionnaire, this model and questionnaire were selected to present and assess family functioning in the conducted research. One of the most accepted models of family functioning is Olson's Circumplex Model [20,21]. This marital and family system model has been widely used for 25 years and consists of three dimensions: cohesion, adaptability, and communication [12]. figure 1 shows a schematic representation of this model.

This research aims to determine the connection between success in mathematics and physics and family functioning. The importance of the research subject is reflected in the basic educational tasks of mathematics and physics, which encourage the development of formal logical and hypothetical-deductive thinking. Therefore, it was considered important to examine how family functioning affects student achievement in these two subjects, which often require more intensive work and cooperation between parent and child due to their complexity. As it is clear that this cooperation directly depends on the relationship within the family, the following

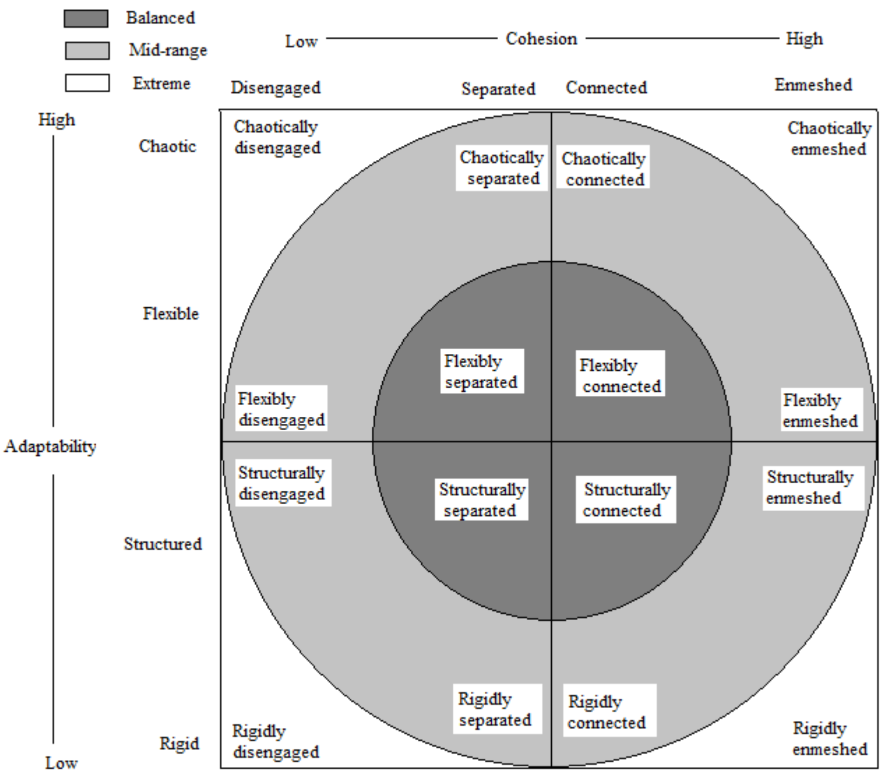

Figure 1. Schematic representation of Olson's model.

research tasks have been formulated:

- Determine whether there is an impact of family numbers on scores on FACES IV scales.
- Determine whether there is an impact of parental marital status on scores on the FACES IV scales.
- Determine whether is an impact of parent education on scores on the FACES IV scales.
- Determine whether there is a correlation between scores on the adaptability scale and achievement in mathematics.
- Determine whether there is a correlation between scores on the cohesion scale and achievement in mathematics.
- Determine whether there is a correlation between scores on the adaptability scale and achievement in physics.
- Determine whether there is a correlation between scores on the cohesion scale and achievement in physics.

2. Materials and methods

2.1. Participants

The study involved 80 respondents, i.e., 31 (38.8%) boys and 49 (61.2%) girls, seventh and eighth-grade students of the elementary school "Ivo Lola Ribar" and the elementary school "Branko Radicevic" in Novi Sad, i.e., children aged between 13 and 15 years. Data were collected in early 2019.

2.2. Assessments and measures

FACES IV is the latest version of the family self-descriptive questionnaire, designed to measure cohesiveness and family adaptability, which are the central dimensions of the circumplex model of the marital and family system. The questionnaire consists of 62 items. Within each item, a 5-level Likert scale was given, within which the respondents expressed their (dis) agreement with the given items. Two additional scales are integrated into the FACES IV questionnaire to obtain more information - the family communication and satisfaction scale. The questionnaire did not include questions about family finances due to the assumption that respondents would not be able to answer correctly. No parent was a teacher or scientist in the field of physics and mathematics, therefore this variable was not taken into account but only their level of educational status. For students' achievements in mathematics and physics, their concluded grades in the semester were taken.

2.3. Statistical techniques

The sample structure and average values on the scales in the questionnaire are presented in the measures of descriptive statistics (frequencies, percentages, arithmetic mean, and standard deviation). The Kolmogorov-Smirnov test assessed the normality of the distribution, and it was shown that the data distribution deviates from the normal distribution. Since the data are not normally distributed, the differences according to different criteria were examined by the Mann-Whitney test for independent variables with two levels and the Kruskal-Wallis test for variables with more than two levels. The correlation was calculated using the Spearman correlation coefficient. To determine the appropriate statistical values, the SPSS program was used.

3. Results

The average scores achieved on the two balanced scales of the FACES IV questionnaire were converted to percentile scores using a conversion table and show that the family members of the respondents are connected and flexible. On the other hand, on unbalanced scales, percentile scores indicate a low level of rigidity, disunity, chaos, and networking. Family communication is at a high level which means that family members feel good about communication and care little. Family satisfaction is moderate, i.e., family members are somewhat satisfied and enjoy some aspects of family functioning (table 1).

3.1. Differences by groups on the FACES IV questionnaire scales

Nonparametric tests determined differences between groups to parental education, and it was shown that parental education significantly affects achievement on the chaotic dimension. Namely, children whose parents have completed primary school achieve the highest results in this dimension, followed by children whose parents have completed higher school, and children whose parents have completed secondary school or college have equal scores (table 2). On other scales, the differences are not statistically significant.

When it comes to the influence of the number of families on the results on the scales, it was found that in families with more members (more than 4), disunity is most present. Children

Table 1. Mean values and percentile scores on the FACES questionnaire scales IV.

	Row	score	Percentile	score
	M	SD	M	SD
Balanced cohesion	27.88	4.63	60.46	26.56
Balanced flexibility	25.19	4.33	61.44	20.86
Disunity	18.03	4.75	34.03	16.00
Networking	16.55	3.76	28.66	10.65
Chaos	16.00	4.09	27.60	12.39
Rigidity	19.67	3.96	38.22	14.08
Family communication	38.26	7.79	61.15	28.16
Family satisfaction	38.79	7.10	58.83	28.32

Table 2. Differences on the scale of chaos towards parental education.

	Md Primary school	Md Secondary school	Md College	Md Faculty	χ^2	p
Chaos	19.00	15.00	17.00	15.00	11.05	<.05

Table 3. Differences on the scale of independence according to the number of families.

	Md With one parent	Md A family of three members	Md A family of four members	Md Multi-member family	χ^2	p
Disunity	17.00	17.00	17.00	23.00	8.81	<.05

Table 4. Differences on scales according to the marital status of parents.

	Md Married	Md Divorced	Md In an extramarital union	χ^2	p
Flexibilily	26.00	23.00	24.00	7.54	<.05
Chohesion	30.00	26.50	27.00	11.61	<.05
Family communication	41.00	32.00	39.00	8.76	<.05
Family satisfaction	41.00	31.50	37.00	10.41	<.05

living with only one parent achieve the same results in families of three or four members (table 3). The number of family members did not prove significant when it came to scores on other scales.

Parental marital status has a statistically significant effect on flexibility, cohesion, family communication, and family satisfaction. Children whose parents are married score significantly higher on all four scales, followed by children whose parents live in an extramarital union. The worst results are achieved by children whose parents are divorced (table 4).

3.2. Relationship between scores on questionnaire scales and grades in physics and mathematics

Respondents had high and approximate grades in both subjects, so in physics it was M = 3.85 (SD = 1.13), and in mathematics it was M = 3.81 (SD = 1.22). The largest percentage of respondents spent on practicing physics is up to half an hour (43.8%), and a significant percentage of them practice physics for up to an hour (40%). While for mathematics, an equal number of respondents practice for half an hour and an hour (36.2%). Most respondents do not help their parents exercise (63.8%), but some seek help from their father (12.5%) or mother (23.8%). In situations when their parents help them, they usually spend up to an hour learning (46.4%), and a significant percentage work with their parents for up to half an hour (39.3%). Since the data obtained on the questionnaire scales and grades in physics and mathematics deviate from the normal distribution, the correlation was analyzed using the Spearman correlation coefficient. The results indicate that there is a negative relationship between the scale of networking (r_o = -.23, $p < .05$) and chaos (r_o = -.27, $p < .05$) with grades in mathematics. In other words, low levels of chaos and networking follow higher grades in mathematics. When it comes to grades in physics, they are positively related to the scale of balanced cohesion. Namely, high results on this questionnaire scale are followed by high grades in physics (r_o = .28, $p < .05$). So, the lower the level of chaos, i.e., the higher the level of cohesion, the students achievement are higher.

4. Discussion

The results of the research show that the largest number of respondents live in families of four. If the family functioning of these families is taken into account, it is noticeable that in families with more members (more than 4), disunity is most present. Children living with only one parent, in families of three or four members, achieved equal results on this scale, and the number of family members did not prove to be significant when it comes to scores on other scales. No statistically significant difference was found between the number of family members and the success in mathematics and physics. The "unfavorable number of children" in the literature is often associated with risk factors for poor school performance in general, as well as juvenile delinquency [22, 23]. A larger number of children can represent a greater burden for parents and a severe difficulty in educational activities, providing material resources and conditions necessary for adequate development of children. The only child in the family is at risk of wrong upbringing, given that excessive parental love, indulgence, fulfillment of various requirements leads to the creation of a spoiled, egocentric, antisocial, or nervous child who avoids socializing with peers and relies too much on parental support [24]. If the order of birth of children is taken into the equation, previous research shows that first-born children usually have good relations and good communication with their parents and a high degree of aspiration for school success. Also, due to the attention paid to him by both parents and older siblings, the youngest child in the family rarely achieves poor academic success. The greatest fear of poor school performance exists in middle-aged children, who are not entrusted with responsibilities and important roles, as is the case with first-born children, nor are they tolerated irresponsible behavior, as is the case with the youngest children. The reason for poorer school success in high school children can be found in the amount of attention and help that parents give them. Compared to the oldest and youngest children, middle children receive the least amount of parental attention and often find an inadequate way to attract that attention, such as poor school performance, problematic behavior, and juvenile delinquency [25, 26]. The results obtained by this research confirm the problems in the family functioning of families with more children, which is reflected in the form of family disunity, but despite aggravating factors, these students achieve the same results in mathematics and physics as their peers from smaller families. This emphasizes the importance of proper preparation of future teachers and the need to provide support to teachers in their work [27] to adequately respond to work with such children and encourage them to adequately respond to work with such children their proper cognitive development. Also, the results show that the largest number of parents of respondents lives in marriage, while the least of them live in an extramarital union. Parental marital status proved to be statistically significant on the scales of flexibility, cohesion, family communication, and family satisfaction. Children whose parents are married score significantly higher on all four scales, followed by children whose parents live in an extramarital union. The worst results are achieved by children whose relatives are divorced, which is in positive correlation with Anderson [28]. If the success in mathematics and physics is taken into account, the research shows that low levels of chaos and networking

Journal of Physics: Conference Series **2288** (2022) 012028 doi:10.1088/1742-6596/2288/1/012028

(intertwining) are followed by higher grades in mathematics, while high grades follow high results on the cohesion scale in mathematics. These results are expected, given the research to date. Namely, the structural completeness of the family is considered an important precondition for its adequate functioning. The active participation of both parents in children's upbringing enables several important elements for the child's proper development but provided that there is also an emotional connection, support, and solidarity both between the spouses and in the parent-child relationship. Therefore, families with only one parent have more difficulties, especially if the missing parent plays an important role in the family's life [29]. Children from these families show poorer general academic achievement. Of course, an important factor is a reason for the absence of one of the parents. The reason for family incompleteness can be the abandonment of the family by one of the parents, the death of one parent, the absence of the parents for objective reasons, or illegitimate birth. It is also necessary to consider what kind of family atmosphere preceded that event, at what age of the child the loss of one of the parents occurred and whether that loss was adequately compensated. Structural incompleteness of the family, which is caused by factors outside the influence of the family (loss of parents due to death, for example), does not lead to a negative effect on family functioning and development and school success of the child, as much as structural incompleteness caused by subjective factors (divorce, leaving the family) [25]. Naturally, families in which one parent bears all the educational responsibility also show difficulties in the child's school success. A single parent, trying to provide material means for the adequate functioning of the family, usually does not have enough time to dedicate to their child, encouraging their school success and thus practicing mathematics and physics with them. In families with both parents, these responsibilities should be optimally distributed, and in that case, the child's school success is not lacking, both in general and in mathematics and physics. When it comes to parent education, the conducted research shows that the largest number of parents included in the research had completed high school, while a slightly smaller number have completed high school or university, and only two respondents have parents whose highest level of education is primary school. No parent was a teacher by profession or a scientist in the field of physics and mathematics, therefore this variable was not taken into account but only their level of educational status. Nonparametric tests determined differences between groups with parental education, and it was shown that parental education significantly affects achievement on the chaotic dimension. Namely, children whose parents have completed primary school achieve the highest results in this dimension, followed by children whose parents have completed higher school, and children whose parents have completed secondary school or college have equal scores. The differences obtained on other scales are not statistically significant. High scores on the scale of chaos are closely related to the grade in mathematics; a worse grade in mathematics accompanies higher scores on this scale. These results are also expected, considering the previously mentioned factors that affect the school achievement of students and results from other research listed by Shamama-tus-Sabah et al. [30]. Parental education has proven to be an important factor for students' school success in previous research. The literature believes that children whose parents have higher education achieve higher school success due to the higher involvement of parents in education and school obligations of the child. Parents with a higher level of education are also better motivators for school success, a better example, and a model for their children. Parental aspirations and expectations are a critical factor for a child's school achievement and their self-belief, their expectations, which are decisive factors for general school success, and thus success in teaching mathematics and physics [31]. Parental aspirations and expectations are a critical factor for a child's school achievement, but also for their self-belief, their expectations which are decisive factors for general school success, and thus success in teaching mathematics and physics [31]. Parents who have a lower level of education have fewer intellectual resources and modest potential for creating an educational stimulating atmosphere and assisting children in successfully overcoming school obligations. However, some earlier research shows different results. Namely, research conducted by the author Kahl shows that parents who are not satisfied with their level of education encourage their children to achieve better school success [32]. Also, research conducted by Krauss [33] shows that uneven parental education (one parent has a higher and one lower level of education) leads to the disagreement between parents, which is further transmitted to the child in the form of greater motivation and higher aspiration for school achievement. However, the results obtained by this research are in line with the literature and logical. Parents with a higher level of education are able to help their children with their responsibilities related to teaching mathematics, practicing, and clarifying mathematical tasks. The results of this research also show that the average grade in both physics and mathematics is very good, as well as that students usually spend between half an hour and an hour during the day practicing mathematics and physics. Most of the students practice the tasks from these subjects on their own, and if they ask for help from their parents, they more often ask for it from their mothers. When their parents help them, it is also usually between half an hour and an hour a day. Finally, the research confirms the existence of a negative relationship between the scales of networking and chaos and grades in mathematics, so that high grades follow low levels on these scales in mathematics, and high levels on the scales go hand in hand with worse grades in mathematics. However, the scores achieved on the scales of chaos and networking are quite low, and most students still rate family communication as good, and family satisfaction as moderate. According to Olson's Circumplex Model, family cohesiveness refers to family members' togetherness and emotional connection. On one side of the spectrum, there is excessive networking and on the other is disengagement among family members. At the center of the cohesion, spectrum is a healthy level of family connection about separation [12]. Also, families that show high levels of networking are families whose members are too focused on each other, not independent, with little social interaction. The family functioning of these families is therefore disrupted, which hinders the child's adequate development and school achievement. According to the literature, students from these families are enterprising, overly dependent on their parents, unsocialized, "spoiled", which are risk factors for problems in the academic achievement of students. The results obtained by this research also show that the grade in physics is directly related to the scale of balanced cohesion, which means that students whose families show family functioning filled with a healthy dose of connection and allowing separation have a higher grade in physics. However, given the lack of research on this topic, it is necessary to investigate this relationship more closely in the future. The situation is similar to the results obtained on the scale of chaos. Chaos in the Circumplex model represents one end of the spectrum of adaptability or flexibility, while there is excessive rigidity at the other end of the spectrum. The characteristics of family functioning of families with high levels of chaos are variable leadership, and family decisions are made impulsively and recklessly. Thus, the negative association between math grades and scores on a chaotic scale is logical, as earlier research shows that students need structure, consistency, daily parental guidance, and safety for optimal school success. Chaotic families do not possess these qualities, so poorer general school success is expected, further referring to mathematics success. It is important to state here that the Circumplex model most often criticizes the very concept of the scale of chaos. Adaptability is a term in family functioning that has so far been considered exclusively positive, and many authors resent Olson's definition of chaos as a high level of adaptability [34]. This research was one of the first studies dealing with the relationship between family functioning and grades in mathematics and physics. For further research, it will be needed to take a larger and more diverse sample.

5. Conclusion

Previous research agrees that the family environment is an important factor determining students' development, functioning, and school success. The role of the teacher in the educational system, in addition to the transfer of knowledge, includes encouraging and directing the development of students, which is possible only if the teacher is able to see and understand all the factors that could affect him. Therefore, understanding the connection between students' achievement in school subjects in mathematics and physics and family functioning is important for teachers to develop competencies to adequately respond, encourage and motivate students, to achieve optimal school achievement. The results of the research confirm the existence of differences in family functioning according to the number of children and the education and marital status of parents. Such results are consistent with the literature. The authors, who deal with the connection between family structure and school success, state the term "unfavorable number of children", and consider the number of family members and the order of birth to be an important predictor of school success. Parental education is also a repeatedly confirmed factor that affects both the level of motivation and the level of aspiration of students. Family incompleteness is considered a risk factor for poor academic performance and the occurrence of juvenile delinquency. The research aimed to determine the connection between the scores on FACES-IV scales and the success in mathematics and physics. The results indicate that there is a negative relationship between the scale of intertwining and chaos with grades in mathematics, as well as a direct correlation between the results on the scale of balanced cohesion and success in physics. Such results are expected, given that a healthy family is considered a prerequisite for good student success in the school environment. However, previous research on this topic is small, so it is necessary to conduct more extensive research that would confirm the results.

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Scientific concepts related to physics from the perspective of students of biology

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Abstract. In many studies, special attention is paid to examining how students acquire scientific concepts and use scientific terminology. Proper understanding of scientific concept is in direct correlation with the quality of students‘ knowledge. The knowledge composed of irregularly adopted concept leads to misconceptions. The aim of the research was to examine how students of biology understand certain scientific concepts in physics that are relevant to their profession. Also, it is examined their intrinsic motivation for physics using a standardized questionnaire. This research was conducted in February 2016. The research results pointed that students do not understand some basic concepts related to physics, but students' motivation for learning physics is on a medium level.

1. Introduction

The aim of modern institutional education and teaching as its primary form of organized formation, represents a complete and logically consistent system of knowledge and concepts for students, as well as the outcome of the educational process in the classroom [1, 2]. In many studies, special attention is paid to examining how students acquire scientific concepts and use scientific terminology. Proper understanding of scientific concepts is in direct correlation with the quality of students‘ knowledge [3]. The knowledge composed of irregularly adopted concepts leads to misconceptions. According to Bryan et al. [4], motivation for learning science have benefits for all students by fostering their scientific literacy, which is the capability to understand scientific knowledge, identify important scientific questions and draw evidence-based conclusions. Because of such a large impact of motivation on the learning process, many studies have searched for the most appropriate ways to measure students‘ motivation and examine the validation of different tests. Some of these articles are [5–8]. Motivation affects the reason students learn and the intensity and duration of activity and learning. Therefore, motivation can be defined as a multidimensional phenomenon that manifests itself through the choices of objectives, level of investment of effort and perseverance [9]. Motivation is broadly conceptualized as the ‘drive‘ that directs students‘ learning, whereas engagement refers to the actual learning processes and behavioral, affective, and cognitive indicators [10]. Social cognitive theory, developed by Bandura and extended by others, explains human learning and motivation in terms of reciprocal interactions involving personal characteristics, environmental contexts, and behavior [4]. This paper uses just three motivation components (intrinsic motivation, self-efficacy, and self-determination) that play important roles in the learning of science and represent personal characteristics. Intrinsic motivation is the inherent satisfaction in learning science for its own sake; self-efficacy is students' belief that they can achieve well in science, and self-determination is the control students believe they have over science learning [4].

2. Materials and methods

Students often seen physics as difficult and do not understand the concepts they adopt. So, the aim of the research was to examine how first year students of biology understand certain scientific concepts in physics that are relevant to their profession. Examined concepts students learn during high school but it was noticed that they do not properly understand them. Because causal relationship between students proper understanding of physics concepts and their motivation, it is examined students' intrinsic motivation for learning physics using a standardized questionnaire. Discovering this connection was considered an important issue because student lack of motivation directly affects their choice to study.

2.1. Research tasks

- Determination of the extent to which students understand some basic concepts of physics.

- Examination of the intrinsic motivation of students to learn physics.

2.2. Hypotheses of research

- It is assumed that students will give the correct answer to the question related to understanding some basic physics concepts (isotropy, indicative, thermal equilibrium, normal distribution, resolution).

- It is assumed that most of the students will show a medium level of motivation which is in paper [5] define as sometimes to often motivated.

2.3. Instruments

A questionnaire developed from Glynn (Science Motivation Questionnaire) was applied to examine students' motivation for learning physics. It is used questionnaire presented in paper [4]. The questionnaire contains 14 items related to the three components: intrinsic motivation, self-efficacy, and self-determination. The instrument is made in the form of a five-point Likert scale. Students responded by circling the number on the scale representing their opinions, from complete agreement-marked by number five to complete disagreement-marked by number one. The test for determination students understands a basic concept of physics contains 13 items. The Cronbach's alphas of the motivation-component scales were α motivation = 0.772 and for concepts question were α concept = 0.648.

2.4. Participants

This study was conducted at the Faculty of Sciences, University of Novi Sad, and the sample consisted of 89 biology students, which are 79% of all population. This research was conducted in February 2016 at the beginning of the course Biophysics in order to determine their knowledge and misconceptions about physics concepts which they learn during high school. Data were analyzed by using SPSS Statistics 20.

Table 1. Components for factor analysis.

Component	Eigenvalue	% of Variance	Cumulative %
1	3.77	26.91	26.91
2	1.72	12.27	39.17
3	1.45	10.34	49.52

3. Results

Since the goal of this study was dual, therefore the results are divided into two parts. One part shows students‘ understanding of scientific literacy related to physics, while the other is related to students‘ motivation for learning physics. The results have shown that students properly adopted concept of isotropy, indicative and thermal balance. 76% of surveyed students give the correct answer to the question isotropy. With the concept of isotropy students of biology encountered in the context of explanations of muscle cells and skeletal musculature. The observation of striated muscle cells in the polarization microscope showed lighter and darker colored stripes characterized by isotropy or anisotropy. Approximately 73% of students answered the question indicative correctly. With the concept of indicative, students have met in the framework of teaching chemistry using litmus paper. Determination of acidity of the environment using litmus paper is often used in biology. It is important to determine in what kind of environments growing plants or with what kind of agency is necessary to act in order to foster the growth of plants or destroy certain bacteria. The third concept that students are clearly defined is the concept of thermal equilibrium. Approximately 78% of students answered correctly to questions relating to this concept. The results have shown that students did not properly adopetd the concepts of normal distribution, resolution, and latency. Graphic presentation of the results and their interpretation was a significant problem for the students. Students mainly were wrong regarding this question. According to their beliefs, the normal distribution is identified with the equilibrium (around 25%) or the equivalent condition (around 16%). While for 36% of students, the normal distribution represents the relevant condition. The second concept that the student did not properly understand is the concept resolution. For them, the resolution is the power of dissolving the little details (27%) or the power of merging the little details (28%). In addition to these two concepts, students were ordered to incorrectly accepted the concept of latent. Around 47% of respondents believe that this concept means slowly. Not knowing the concept is a questionable understanding of transport processes related to heat transfer and energy. Interestingly, they correctly perceived the concept of thermal equilibrium but incorrectly concept related to heat transfer. The data indicate a serious failure not cultivating scientific literacy. By leaving out the properly understood concepts, mis-conceptions are formed that adversely affect the quality and quantity of students‘ knowledge. Hypotheses of research were partially confirmed. ANOVA did not show a statistically significant difference in the number of correct answers with the grades in physics at secondary education $F(3,85) = 0.224$, $p > .05$. In this research, it was also examined students‘ motivation for learning physics. For data processing, factor analysis is used. All factor loadings show values above 0.3 on their main factor; the KMO value of 0.68 indicates distinct and reliable factors. The Barlett test was significant ($p < .001$), indicating that correlations between items are significantly different from zero. By using the Kaiser criterion, it is allocated three factors (table 1). The obtained component describes about 50%.

Table 2 shows the values obtained by factor analysis.

Factor 1 presents the intrinsic motivation; factor 2 – self-efficacy; factor 3 – self-determination. It was obtained the average values of obtained factors (table 3).

ANOVA showed that there was no statistically significant difference in the student‘s motivation depending on the grades in physics at secondary education $F(3, 85) = 2.54$, $p >$

Table 2. Factor analysis.

Number of question	Factor 1	Factor 2	Factor 3
13	.737		
14	.700		
7	.679		
11	.585		
2	.507		
1	.485		
3		.831	
8		.794	
5		.651	
6		.328	
4			.831
12			.778
9			.539
10			.466

Table 3. Descriptive analysis.

	M	SD
Factor 1	3.33	0.61
Factor 2	2.99	0.65
Factor 3	3.79	0.53

.05. The results obtained that the less motivated were students who had grade good and very good, while greater motivation showed students who had grades sufficient and excellent. This is a very interesting fact that students with low grades in physics perceived greater motivation for learning physics. In order to determine the influence of students‘ motivation on the accuracy of responses, ANOVA was used. ANOVA did not show a statistically significant effect of motivation on the accuracy of responses $F(3,85) = 2.42$, $p > .05$, but by using descriptive statistics can be observed some differences (Figure 1). Students with less motivation for learning physics have less precisely answered questions related to the knowledge of the concepts, while students with higher motivation for physics have more precisely answered the same questions. The obtained data indicated that if the students showed higher motivation for learning, they would achieve better results, which further stimulated increasing motivation [11].

Therefore, to improve the teaching of physics is necessary to primarily detect positive and negative factors affecting students‘ motivation and apply those teaching instructions that stimulate motivation to impact students‘ knowledge positively.

4. Discussion

Starting with Piaget and Vygotsky, many researchers have been interested in explaining the development of the concept because they represent a basic element for learning principles, understanding hierarchical relationships, and organizing and developing thought processes [12]. Therefore, during explaining a phenomenon or concluding about hierarchical or causal relations, words-concepts are used in the function of formal abstraction, i.e., spatial verbalization of what is already given as such in representations or perceptions or its practical experience [13]. When the complexity of the development of the concept is viewed through the prism of natural sciences, then the researchers are interested in presenting the studied phenomena related to certain concepts in the most transparent possible way, using various teaching approaches [14–17].

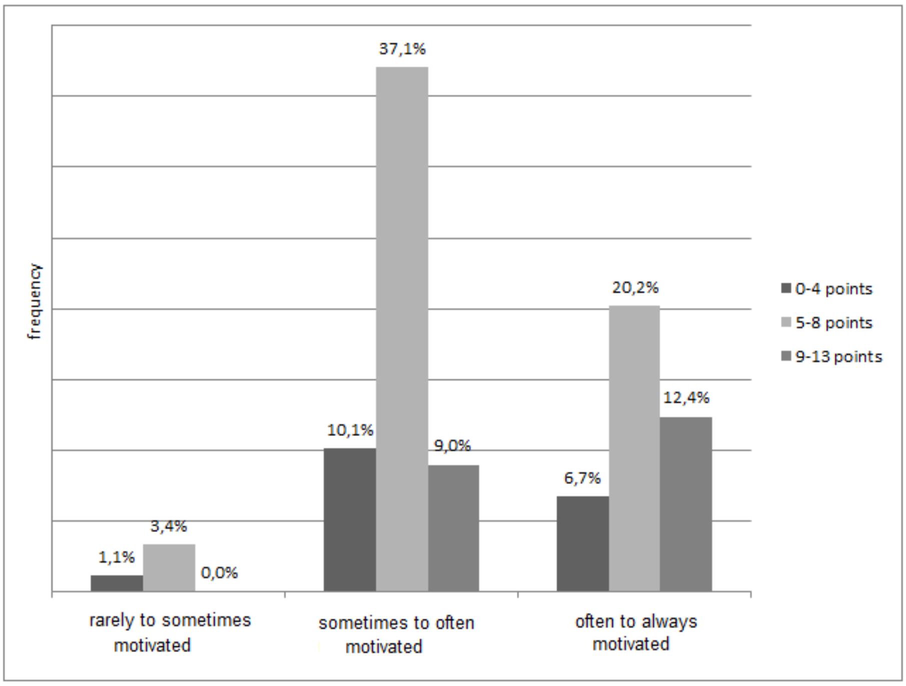

Figure 1. *Impact of motivation on the accuracy of responses*

The need to achieve greater scientific literacy is highlighted in 21st-century skills [6]. However, although it constantly emphasizes the importance of a correct understanding of physical concepts and phenomena that describe our movement on Earth and much wider, the motivation for this subject and the general student achievement in physics is small. Moreover, according to [18], the results of numerous studies state that the reason for the low uptake of Physics is the perception of irrelevance and that the discipline is conceptually abstract and a difficult subject to learn. Therefore, this research aimed to bring together these two important but causally related issues; students‘ understanding of physical concepts and their motivation for learning physics. Obtained results have shown that students properly adopted some concepts (isotropy, indicative, and thermal balance), but some of the concepts (normal distribution, resolution, and latency) are still unclear for them. This means that students do not see physical law as describing a physical phenomenon rather than just seeing setting theories without its applications. This result emphasizes the importance of using more modern approaches to high school teaching that will show in more obvious ways the practical applications of the studied theoretical concepts. The application of newer approaches will cause a change in the position of students in the learning process and will cause greater motivation to learn [19, 20]. The results of this study showed that students showed slightly higher self-determination and intrinsic motivation, while self-efficacy was the lowest. Therefore, it can be suppoused that application of new approaches in teaching high school physics will cause higher increasing of motivation to learn physics and better understand physics concepts.

5. Conclusion

This research aimed to determine the level of knowledge of the basic concepts used in physics, students‘ motivation for learning physics, and to determine the potential impact on the motivation of students‘ response accuracy when defining a concept. Certain incorrectly adopted concepts indicated the need to change the educational content and encourage more evident connections between materials.

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STEM centre as a factor in the development of formal and non-formal STEM education

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Abstract. The article is devoted to the study of STEM education. It is one of the important directions of educational reform of the XXI century and can be implemented through the integration of formal and non-formal education. The authors of the paper study the ecosystem of formal and non-formal STEM education. Researchers have identified the main characteristics of this ecosystem such as the harmonious combination of formal and informal components of STEM learning, increasing the motivation of students to STEM sciences, constant updating of educational programs and professional development programs for teachers; use of non-formal education approaches; constant connection with external communities of STEM professionals; building partnerships between schools and non-formal institutions. The authors have developed the main components of the model of functioning of the educational STEM centre as an education ecosystem. In particular, they are educational research, assessment (evaluation), research projects, innovative teaching methods, programs for training, undergraduate education, teacher training, mentoring, services, communications, cooperation, infrastructure, connection, networking. To assess the extent of the impact of various forms of formal and non-formal learning activities on the results of the implementation of STEM education, an expert survey was conducted. The results of the survey are systematized, illustrated with the help of infographics, statistically significant relationships between individual parameters of the proposed model are established. To test this model in practice, an experiment was conducted. It lasted from 2016 to 2020. Researchers have confirmed the hypothesis that STEM education gives the best results due to a combination of formal and non-formal levels. Therefore, their STEM centre promotes STEM education among the general public, training and retraining of educators involved in STEM, development of STEM competencies of pupils and students.

1. Introduction

21st century society is changing quite rapidly. It requires an appropriate level of education. Traditional formal education may not always provide the necessary opportunity to overcome learning problems. As a result, both formal and non-formal education are becoming increasingly important. In the countries of the European Union, considerable attention is paid to the legislative regulation of non-formal education. The development of non-formal education is facilitated by such world organizations as the United Nations, UNESCO, the European Union, the Council of Europe and others. The Memorandum of the European Commission provides recommendations for the development of non-formal education, which is an important component of the concept of lifelong learning, allows young people to acquire relevant competencies and adapt to the challenges of modern society [1].

Non-formal education is a complement to formal education and is necessary to increase the positive attitude of pupils and students to their meaningful knowledge in various fields, in particular it is relevant for the STEM field. There are a growing number of non-formal STEM subjects (science, technology, engineering, math) around the world. The United States spends more than 3 billion dollars a year on STEM education, with 32 percent of that amount (157 millions dollars) spent on non-formal STEM education [2]. Non-formal learning STEM events for children are organized in different places and contexts, such as museums, libraries, computer clubs, Fab Labs, youth centres, conferences or universities [3].

2. The literature overview

In recent years, various countries have gained extensive experience in the development of STEM education. Analysis and research allow to summarize and present its most significant characteristics. American education strategists T. Lund and M. Steins say there is no need to try to integrate STEM activities into existing learning units. Instead, traditional content blocks should be deconstructed and existing experiences reconstructed using innovative methods of both formal and non-formal STEM learning [4].

To enhance the positive behavior of students in the STEM field, non-formal education has been recognized as a necessary complement to formal education received at the school. J. Petnuchova [5] defined non-formal education as a learning process that is initiated by individuals and is a by-product of more organized activities. It may not have specific learning objectives. A visit to a museum, a summer technology camp and a Girl Scout are examples of non-formal education. Non-formal education allows students to study in a calmer environment, with greater readiness and less structure compared to formal education received at school. These benefits provide the high potential of such training. Mohr-Schroeder et al. reported that students are more interested in choosing a STEM field for a career after participating in non-formal STEM education [6, 7].

Experts J. McConnell and T. Kelly note that a better future for STEM education requires well-trained and proactive teachers who can share their knowledge and experience in teaching and mentoring students. Therefore, they must constantly receive opportunities for professional development. This will help develop their desire and talent to teach STEM [8]. In particular, Farzana Aslam and others believe that participating in STEM education activities helps teachers understand and develop their own sense of identity as STEM professionals. Educational activities enable teachers to interact with leading scientists and gain access to modern research [9].

Universities also implement professional development programs for teachers. The main goal of these programs is to identify key STEM competencies of teachers for the effective use of non-formal education approaches [10]. Teachers are changing the way formal content is conveyed and thus transforming their own STEM learning experience. This allows students to better understand STEM subjects and improve academic performance [11, 12].

Implementing STEM training is too difficult for any single educational institution. Schools in different countries are actively using non-formal educational activities in the field of STEM [13].

Therefore, museums, zoos, nature centres, aquariums, and planetariums are among the thousands of informal research institutions in the United States that regularly engage young people in observing, learning, and using STEM knowledge and skills. This is because they provide a wealth of resources not available in any classroom. As a result, informal research institutions across the United States have partnered with public schools. Affiliate programs cover a variety of STEM subject topics in primary and secondary school [14].

Lithuanian scholars R. Bilbokaite, V. Slekiene and I. Bilbokaite-Skiauteriene noted that during the implementation of education reform in their country, much attention is paid to the development of non-formal education [15]. That's why STEM centres are being created there. According to the experience of researchers, these centres can attract more than a third of all students. The development of research skills in students justifies the need to create an author's STEM centre with open access. More than 90 percent of respondents agreed to take part in the work of this centre. All these students are interested in in-depth study of physics, chemistry, biology, mathematics, computer science, technology. Therefore, they agree to attend a variety of non-formal extracurricular activities. Researchers have identified that the most interesting forms of learning in the STEM centre are self-tests and experiments, participation in research of scientists, solving practical problems in preparation for competitions, exams, teamwork students.

3. The main results of the study

The STEM centre plays an important role on the Ternopil Volodymyr Hnatiuk National Pedagogical University (TVHNPU) campus. It brings together institutional efforts to create the conditions for STEM learning and support consumers of educational services. Scientists of the Department of Computer Science TVHNPU have created a model of functioning of the educational STEM centre (see figure 1). This model was tested during 2016-2020 at the Faculty of Physics and Mathematics of TVHNPU. Research [16] shows that the centre has become the main educational platform for the development of STEM education in our region. In this

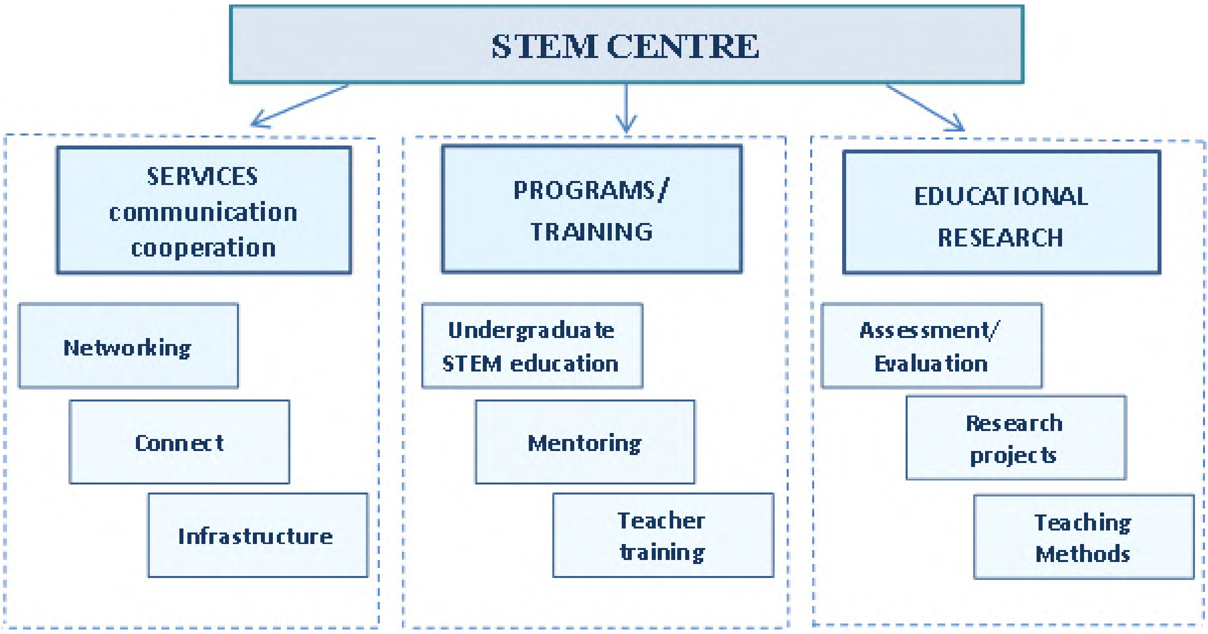

Figure 1. A model of STEM education centre functions.

study, we consider the established STEM centre as an educational ecosystem of formal and non-formal education. We substantiate the use of the concept of ecosystem of formal and non-formal education. Today, the ecosystem approach extends to all sectors of society, including education. The modern model of learning is in crisis. Traditional education needs to change. This is because it is not easy for graduates to find their jobs. One of the solutions may be to develop an ecosystem approach to education and to organize a STEM centre as a provider of such education. Today, the concept of "ecosystem" is still evolving and there is no clear definition. We view the learning ecosystem of formal and non-formal STEM learning as an emerging practice for the future. The educational ecosystem of the STEM centre is a complex entity that includes both the community of education providers and those who learn, develop and evolve, and a new management paradigm for organizing the process of STEM education and training future teachers. This paradigm will help to ensure the maximum realization of the potential of each person and at the same time the maximum demand from society.

We have created a platform for the operation of individual STEM components. The platform was designed and created in a context of diversity of people and initiatives. At that time, there were almost no ready-made solutions for the functioning of individual STEM components as a whole. The STEM Research Centre of the Faculty of Physics and Mathematics has become a place of emergence of initiatives, development of many projects and a platform for communication of various stakeholders. It aggregates resources for teaching STEM disciplines in schools and universities. Members of the centre are constantly searching for methods and approaches to the implementation of STEM, analyze and systematize the various experiences of successful educational STEM practices.

In the process of reforming pedagogical education at Ternopil Volodymyr Hnatiuk National Pedagogical University, we tested and implemented some STEM practices such as

- Cooperation with pilot STEM schools. Each such school has its own unique context, operating conditions, principles. Their implementation characterizes STEM education at the level of an individual school. Scientists of the Department of Computer Science advise the management of individual schools on the implementation of an innovative model of STEM education in their educational institution.
- Effective career guidance among pupils and students. Young people have the opportunity to get acquainted with modern and promising professions, try themselves and decide on their future profession.
- Development of motivating activities such as scientific picnics, Olympiads, competitions, STEM festivals, STEM excursions, STEM workshops, etc.

Let's analyze the main components of the STEM educational centre model as an ecosystem of formal and non-formal education.

Formal component. Educational Research, Assessment/Evaluation, Research projects, innovative Teaching Methods. We focus our research at the STEM centre on improving and enhancing the effectiveness of learning in science, technology, engineering and mathematics through the use of innovative learning strategies. One of the most difficult parts of the STEM curriculum is to create a context for students to gain experience and practice in the process of critical and creative thinking. In our opinion, the use of tools of innovative learning strategies provides an effective methodology for the formation of these high-level thinking skills such as

- Use, recognize and analyze models.
- Focus on inquiry and investigation.
- Communicate effectively.
- Understand multiple connect areas.
- Plan - Act - Understand - Evaluate.

Today we are following such strategies for effective STEM learning.

- Tracking and researching changes over time (changing elements over time, focusing on models and trends).
- Teamwork to solve problems.
- Recognition of the general structure, patterns in different situations (application of ideas in different areas of the curriculum).
- Studying data, finding cause-and-effect relationships.
- Simulation, analysis and data graphs construction.
- Mapping the structure of systems, the use of computer models.

- Use, recognition and analysis of models.

Formal component. Programs/Training. Educational policy in the direction of STEM, educational programs, elective courses. We believe that the basic level of implementation of formal STEM education in the Pedagogical University is the planning of modern educational programs, curricula, individual special courses of choice. Here are some important principles that we use to develop programs for such special courses

- use of "open" tasks that allow students to seek solutions in various fields of knowledge, tasks and problems. There are usually many solutions to these problems;
- moving from solving practical and specific problems to concepts of a higher level of abstraction, ideas and theories;
- use the appropriate mathematical apparatus to find a solution to the problem, focusing on argumentation, proof and logic; application in discussion and solution of problems of digital technologies and computational thinking;
- the possibility of organizing make-up, conducting experiments, constructing from improvised materials using design thinking, engineering design;
- organization of teamwork, presentation of the results to the group, discussion and mutual evaluation in the group.

There is a purposeful reform and correction of educational programs at the Department of Computer Science of TVHNPU. STEM disciplines are included in the programs of specialties "Computer Science", "Mathematics", "Physics", "Chemistry", "Biology". In particular, such special courses are taught as "3D-modeling", "3D-printing", "Design thinking", "Fundamentals of robotics", "STEM projects" and more. They are about the integration of knowledge from different fields, and the development of the practice of students and masters on STEM projects. These special courses are designed to teach students how to solve real problems.

Informal component. Programs / Training. Teacher training. Professional development of teachers in the field of STEM education.

Most teachers receive training mainly in only one discipline. We believe that this is a serious challenge for educators and educational administrators interested in promoting integrated STEM learning. Therefore, retraining of teachers and managers is required to deploy STEM programs. As a result, we organized advanced training of teachers in the STEM centre of the Faculty of Physics and Mathematics. In the STEM centre of TVHNPU we have tested

- training programs for teachers;
- methodologies and methodical materials for employees of educational institutions;
- forms to exchange of experience of teachers practicing STEM education.

These are developments on the introduction of innovative learning technologies, case-technologies, interactive teaching methods, problem-based methods for the development of critical and systems thinking, inquire based learning.

In general, the result of advanced training was the development of STEM education models for different educational levels, the creation of cases of scientific and methodological materials, cases on the implementation of end-to-end STEM subjects and STEM lessons and excursions, mastery of interactive teaching methods, professional competence in STEM training. We believe that training in research STEM practices and the involvement of teachers in real research and engineering university projects "Smart Greenhouse", "Smart Home", "Smart Weather Station" were important. These projects were created jointly by teachers of the Department of Computer Science and Methods of Teaching and students majoring in "Computer Science". All participants in these projects worked together to create models of smart objects, prototyping and researching their capabilities. This means that retraining took place, not in a closed educational system, but in interaction with university scientists. A feature of the practice was the involvement in the educational process of those who can include practice in their actions and show how to do it.

The context and space of modern STEM training is constantly expanding. It is increasingly going beyond the curricula of schools, universities and formal education in general. Ambiguous boundaries between formal and non-formal learning have forced the university and STEM centre researchers to develop clear strategies, practices for combining both formal and various forms of non-formal education such as trainings, workshops, seminars, workshops, excursions, startups, projects, hackathons, distance learning courses, webinars, etc. In the study, non-formal education will be considered in such contexts as Programs / Training. Teacher training; Services. Communications, cooperation.

Non-formal education. Services. Communications, cooperation. Expanding communication on STEM education. The content of this communication is determined by a wide range of issues, from meeting participants, sharing their experiences, identifying problems and difficulties, and ending with communication on new educational content, development of new programs and concepts, etc. Today, a variety of formats of such communication are in demand, such as speeches, discussions on current issues, exchange of experiences and presentation of methods, techniques, practices, working groups and joint projects. All these issues need to be discussed.

In our opinion, various actors must be involved in the promotion and implementation of STEM education. These are government agencies, local communities, small businesses and corporations, individual educational institutions and networks, public associations, associations and professional communities, individual educators. Each of them chooses his strategy of action, taking into account the general situation, their own interests and capabilities.

Such cooperation within the STEM centre was conducted by teachers of the Department of Computer Science of TVHNPU in cooperation with the Institute for Modernization of Educational Content of the Ministry of Education and Science of Ukraine (Kyiv), Ternopil Municipal Methodological Centre for Scientific and Educational Innovations and Monitoring, Ternopil City Administration Education and Science, the Department of Education and Science of the Ternopil Regional State Administration, the Directorate of General Institutions of Secondary Education of the United Territorial Communities.

To create and develop relationships between different actors, we have considered factors such as

- building links between different educational institutions and academic entities to allow students to participate in internships and work on real projects;
- construction of effective communications according to the scheme university - school - community - regional government;
- creating continuity in STEM processes from school to university; this is a factor in increasing the applied value of choosing STEM professions;
- organization of various events for active communication, exchange of experience and search for partners for joint action; creation of resource platforms where new developments, models, samples are concentrated; so they become available for study and application;
- educational management, grants, leadership in education; promoting STEM education among the public and especially among adolescents and other potential stakeholders.

One of the interesting startups to promote ideas about STEM education was the grant project “Promotion of STEM professions”. It was supported by the British Council’s Active Citizens program. Within the framework of this project, the organization of interactive educational excursions, field schools, forums, festivals, STEM workshops took place. The organizers of these events demonstrated new initiatives, achievements and prospects in the development of STEM professions. The startup has increased the awareness of secondary school pupils with some STEM professions. Among them are a 3D printing engineer, an architect of the Internet of Things, a civil engineer. As a result of the project, more than 300 high school pupils from Ternopil and Ternopil region were involved. This project has helped increase the number of students of mathematics, science, technical specialities at universities in our region. We anticipate that universities will be able to train future professionals with STEM skills. They will be ready to implement modern innovative projects in Ukraine and abroad. Conducting educational campaigns aimed at promoting STEM professions will provide an opportunity to realize the creative potential of young people to solve problems in non-standard ways, focusing on the needs of communities, to ensure their sustainable development.

4. Study results and statistical processing

To achieve the research purpose, we carried out a survey study that targeted highly experienced teachers, methodologists and instructors (i.e., experts) of informal and non-formal learning type, who have sufficient experience in the field of STEM education. We followed an intensity sampling approach and collected responses from 130 experts from educational institutions of our region. The experts were recruited electronically through e-mail or were personally approached and invited to participate in the study during various educational events held in the STEM centre of our faculty for educational institutions of the region in the framework of formal and non-formal education.

In order to design our survey, we first investigated the nature of formal and non-formal STEM education across the existing literature and established several dimensions. The study dimensions analysed in this paper, with the related survey questions and predetermined responses categories, are displayed in table 1.

We divided the educational achievements of pupils and postgraduate students into four categories, which we described in more detail in table 2. The postgraduate students are teachers who improve their professional skills in various courses, trainings, seminars, etc.

Experts could make multiple choices by answering questions of our survey. The survey data are entered in the Excel table, which can be accessed using the link `https://docs.google.com/spreadsheets/d/1wvUPRLJKRvhepn_xpVZIxPevLNqRV2cc`. The obtained data were grouped and summarized according to the required criteria for the study. For statistical processing of the received data and their graphic visualization the IBM SPSS Statistics v23 software was used.

Generalized information on the particle (as a percentage of the number of experts surveyed) of subjects in the study of which methods of formal and non-formal STEM education are used is given in table 3. It shows that there are only 2 subjects in which STEM education methods are used the most. This is mathematics and computer science, which is quite natural in terms of the fundamentally of these subjects in STEM education.

According to experts, the goal of educational activities is not always achieved according to the success criteria specified in the survey (see table 4). Experts believe that the result of educational achievements according to criteria P1, P2, P3 and P4 does not exceed 50%. The lowest achievements are according to criterion P4 (Professional and innovative qualities) - 27.69%. This is due to the target audience of the study - primary school pupils, secondary school pupils and teachers who are involved in activities to improve professional skills in the field of STEM education. Students from higher education institutions were not involved in our study, as a completely different list of subjects taken from university curricula should be used to assess their STEM achievements. This is the subject of a completely different study.

In terms of formal and non-formal education, the coverage of curricular subjects is shown in figures 2 and 3.

When using STEM methods of education, the ratio of formal and non-formal learning

Table 1. The investigated dimensions and the related survey items and response categories.

Dimension	Survey question	Predetermined responses
Categories of experts	What category of experts do you belong to?	**PST:** Primary school teacher **SST:** Secondary school teacher **HSL:** High school lecturer **AV:** STEM education ambassador or volunteer **IM:** Instructor or methodologist
Target audience categories	What target audience did you work with in formal and non-formal STEM education?	**PSP:** Primary school pupil **SSP:** Secondary school pupil **PGS:** Postgraduate student
Covered curricular subjects	Please indicate which curricular subjects are covered during the activity	I explore the world / Technology / Mathematics / English (or another foreign language) / Literature / Art / Physics / Chemistry / Biology / Geography / Computer Science / Humanities and social sciences
Learning activity type	What type of learning activity do you use?	Formal Non formal
The purpose of learning activities	What qualities or competencies have you been able to improve as a result of your work?	**P1:** Competences in natural sciences and technologies **P2:** Personal and communicative qualities **P3:** Socio-pragmatic motivation **P4:** Professional and innovative qualities

activities reaches half for most of the subjects covered (see figure 3). Only for the humanities and social sciences, the percentage of non-formal learning activities is much lower (only 28.57%). This is due to the specifics of the subject and the willingness and the readiness of teachers to use the methods of STEM education in teaching their subjects.

If we analyze how much the purpose of educational activities is achieved in terms of STEM education, the following conclusions can be drawn on the basis of survey data (see figure 4). P1 competencies are best formed when using methods of STEM education in such subjects as "I explore the world", "Technology" and "Mathematics". This is a logical conclusion, if we take into account the characteristics of the P1 competences and the content of these subjects. For natural sciences ("Physics", "Chemistry", "Biology", "Geography") and "Computer Science", P1 competencies are observed at the level of 30 percent. The formation of P2 qualities is best manifested (more than 50%) in the study of "English" (or another foreign language), "Literature", "Art" and "Humanities and social sciences". At first glance, the formation of P3 qualities (from 28% to 52%) may seem a bit strange when studying the subjects "Physics", "Chemistry", "Biology", "Geography" and "Computer Science". But this is due to the fact that the study of these disciplines in the framework of STEM education uses the project method, which is often focused on solving practically significant problems of economic, social, environmental content. P4 competencies are formed at the level of 10% to 25% in all subjects,

Table 2. The investigated dimensions and the related survey items and response categories.

P1: Competences in natural sciences and technologies	**P2: Personal and communicative qualities**	**P3: Socio-pragmatic motivation**	**P4: Professional and innovative qualities**
• mathematical competence; • competencies in natural sciences; • interdisciplinary approach, integration of knowledge from different disciplines; • design skills; • possession of digital tools and information technology; • algorithmic thinking; • possession of modern programming technologies	• organizational skills; • ability to cooperate; • ability to make optimal decisions; • developed skills of critical thinking; • use of digital communications; • ability to lead a discussion; • presentation qualities; • ability to reflect	• prospects for successful employment; • the presence of purposeful motivation for creative self-development and lifelong learning; • steady interest in natural and mathematical sciences and engineering (motivation to continue education in science and technology); • vital competencies necessary for successful self-realization; • social and civic activity; • environmental literacy and healthy living	• skills of design and research activities; • mastering the techniques of modeling and engineering design; • ability to select tools, methods and technologies for solving practical problems in accordance with the needs of a particular professional activity; • understanding the importance of STEM education for professional activities; • readiness to accept and implement innovations in professional activities; willingness to solve practical problems that meet the modern needs of society

except “I explore the world”. The subject “I explore the world” is studied in the first grade and at this age it is too early to talk about future career guidance.

As can be seen from figure 5, methods non-formal learning activity in the field of STEM education are most often used (68% - 70%) with primary and secondary school pupils. For teachers who are undergoing training in the field of STEM education, the methods of learning activities in the vast majority of cases (approximately 75%) are traditional, formal.

If you work with the target audience of categories PSP, SSP and PGS within the STEM education, then in 50 percent and more cases the formation of educational achievements

Table 3. Percentages of covered curricular subjects.

I explore the world	Technology	Mathematics	English	Literature	Art	Physics	Chemistry	Biology	Geography	Computer Science	Humanities & social sciences
10.77	15.38	47.69	16.15	13.08	16.15	18.46	15.38	20.00	15.38	52.31	10.00

Table 4. Percentages of the success indicators of learning activities.

P1	P2	P3	P4
46.92	32.31	36.92	27.69

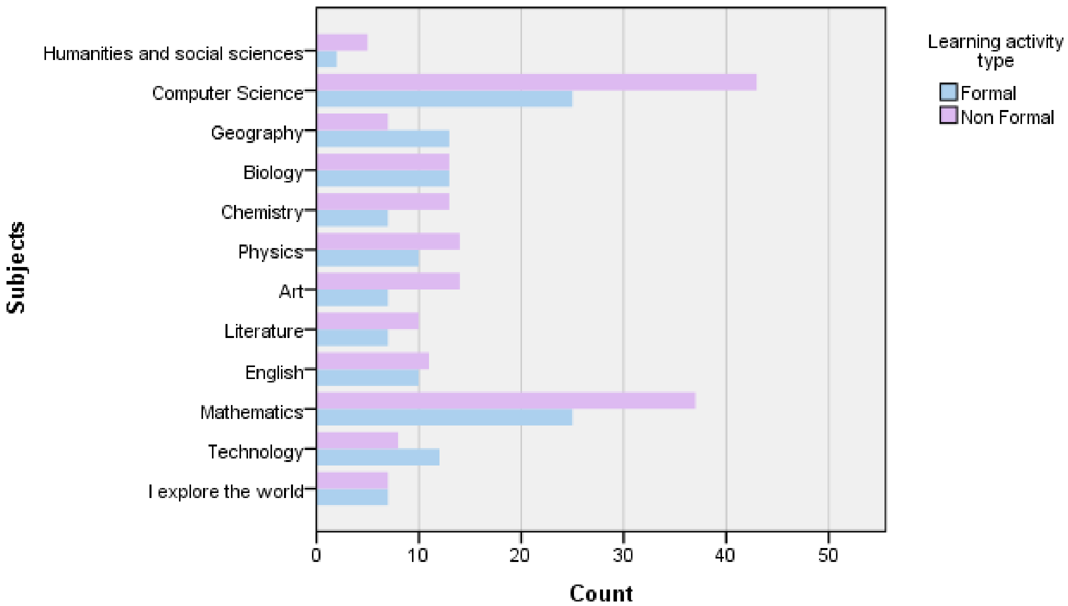

Figure 2. The coverage of curricular subjects by formal and non-formal education (absolute values in the number of observations).

according to criteria P1 - P4 is provided by methods of non-formal learning activities (see figure 6).

For investigating whether the type of the learning activity can be associated with the target

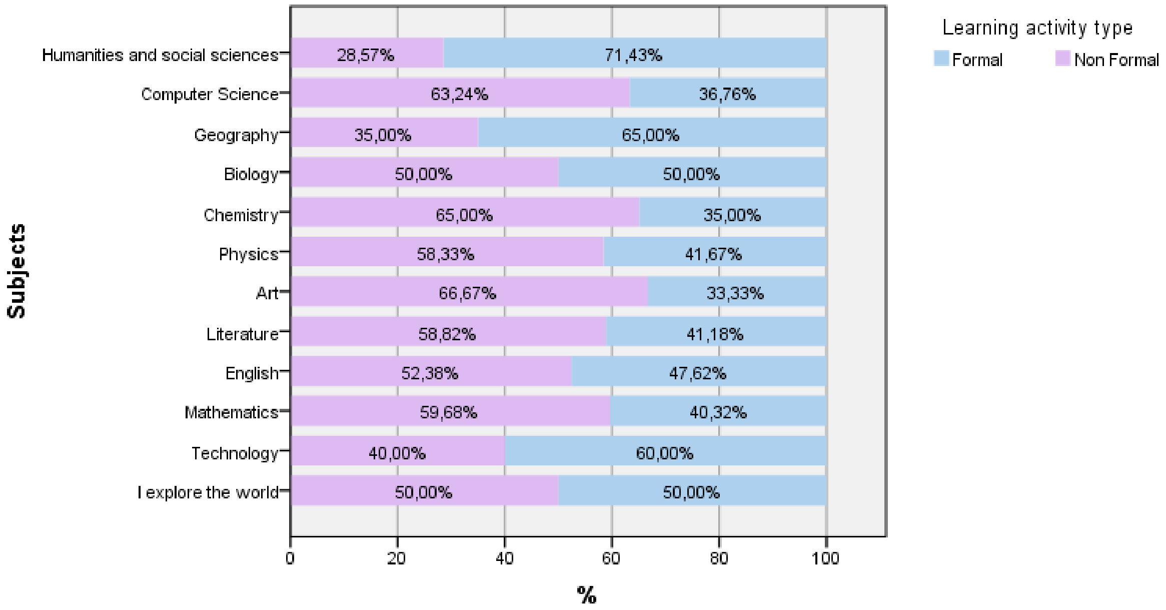

Figure 3. The ratio of formal and non-formal learning activity in the study of curricular subjects.

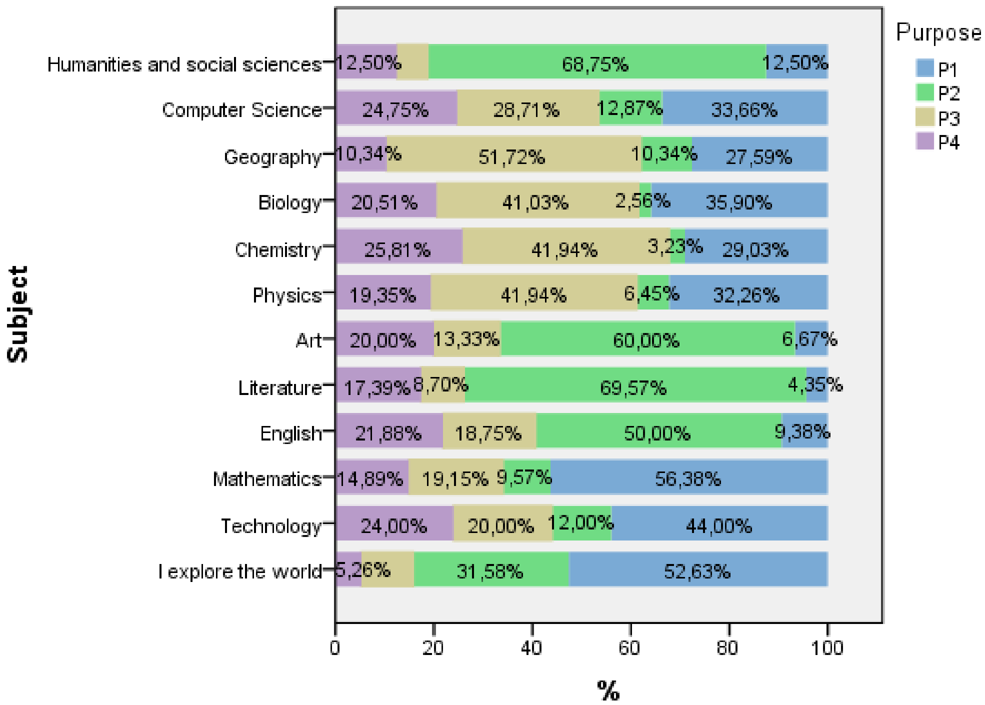

Figure 4. Achieving the purpose of learning activities.

audience, the covered curricular subjects, and the main purpose of the activity, we applied Spearman's correlation analysis. Crosstabulation Subject – Purpose is shown at table 5. At the intersection of rows and columns is the number of relevant observations (cases).

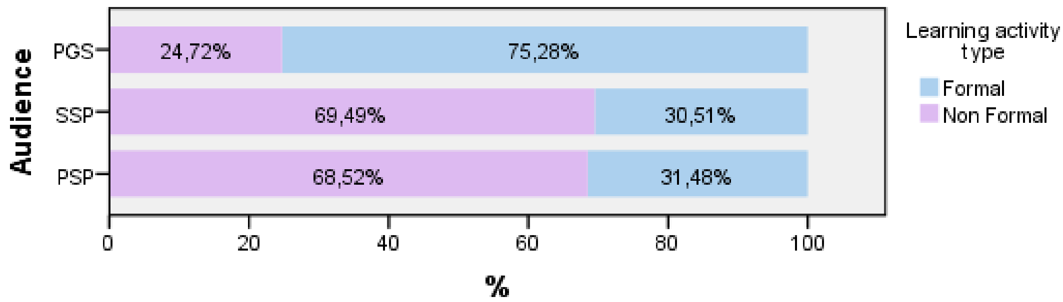

Figure 5. Coverage of the target audience by methods of formal and non-formal learning.

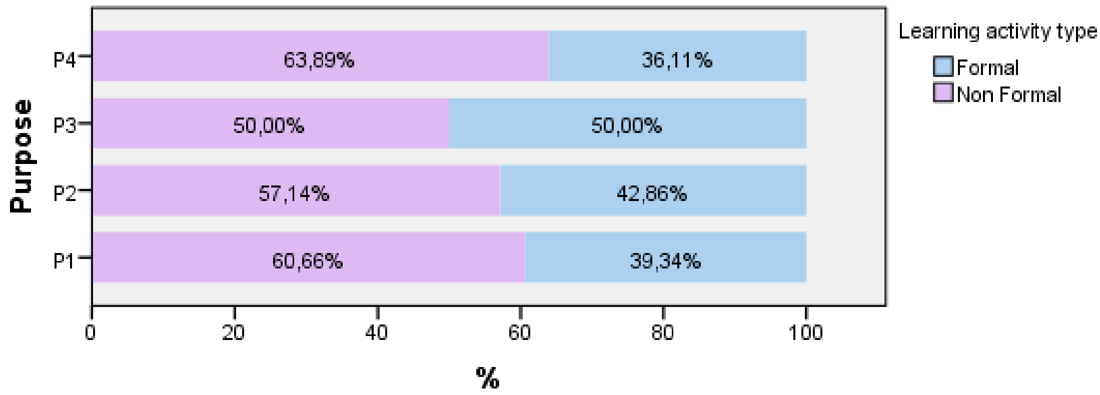

Figure 6. Coverage of the target audience by methods of formal and non-formal learning.

Table 5. Percentages of covered curricular subjects.

Subject	Purpose				Total
	P1	P2	P3	P4	
I explore the world	10	6	2	1	19
Technology	11	3	5	6	25
Mathematics	53	9	18	14	94
English	3	16	6	7	32
Literature	1	16	2	4	23
Art	2	18	4	6	30
Physics	10	2	13	6	31
Chemistry	9	1	13	8	31
Biology	14	1	16	8	39
Geography	8	3	15	3	29
Computer Science	34	13	29	25	101
Humanities and social sciences	2	11	1	2	16
Total	**157**	**99**	**124**	**90**	**470**

The obtained results (r=0.15; p=0.001) suggest that there is a connection between the achieved learning outcomes and the subjects in the study of which the STEM approach was used at the level of significance 0.001 (statistically significant level). The value of the correlation coefficient r=0.15 shows that the relationship between the achieved results and the subjects at this stage is still weak. This situation can be explained by the fact that STEM education is currently at the initial stage of implementation in terms of its coverage of the vast majority of secondary education institutions. There are only a few training centres where STEM education yields significant results, as these centres have a well-developed relevant infrastructure and interested and trained staff. Cramer's coefficient $V = 0.355$ with the level of statistical significance $p = 0.000$ indicates a positive relationship between the purpose of learning and subjects. It is obvious that this connection will be stronger if the STEM approach in the teaching of school subjects is implemented in further with greater concentration of efforts of all persons involved.

Table 6. Crosstabulation Audience - Subject

Subject	**Audience**			**Total**
	PSP	**SSP**	**PGS**	
I explore the world	10	0	2	12
Technology	10	2	4	16
Mathematics	12	26	13	51
English	4	9	5	18
Literature	2	8	5	15
Art	3	8	6	17
Physics	0	17	4	21
Chemistry	0	10	4	14
Biology	0	15	6	21
Geography	0	15	4	19
Computer Science	5	34	15	54
Humanities and social sciences	0	8	3	11
Total	**46**	**152**	**71**	**269**

We examined whether a relationship exists between the target audience and the covered curricular subjects (see Table 6). For examining the association of the variables a chi-squared independence test was used (Cramer's $V = 0.408$, $\chi^2(22) = 89.522$, $p = 0.000$), which shown that significant association between the target audience and the covered curricular subjects exists.

5. Conclusions

The analyzed current domestic and world practical experience in the implementation of STEM education shows that the implementation of STEM - learning is too difficult for any individual educational institution. Therefore, schools in different countries, along with formal, actively use non-formal education in the field of STEM. The main characteristics of the integration of formal and non-formal education are highlighted in the paper. The study created a model of integration of formal and non-formal education at the level of educational environment, content, relevant educational processes and tested it on the example of the functioning of the educational STEM centre as a whole ecosystem. It includes educational research, assessment/evaluation, research projects, innovative teaching methods, programs/training, STEM education policy, educational programs, elective courses, undergraduate STEM education, Teacher training, Mentoring, Services, Communications, Cooperation, Infrastructure, Connect, Networking. The functioning of the research STEM centre of TVHNPU according to the proposed model of the educational ecosystem has led to: creation of a modern educational environment: STEM learning tools, e-learning courses, STEM projects, STEM cases, which provide personal and developmental content of learning; involvement of students in solving real problems and situations by means of computer mathematical modeling, (international project DEDIMAMO); promoting the concepts of STEM education among the general public, increasing the intensity of communication on the topic of STEM education; proper training of teachers and professional development of STEM educators to work in new integrated conditions, development of technological, career and life skills, skills in the field of advanced technologies. The study shows that the results of the introduction of STEM methods of education in the teaching of school subjects are influenced by various forms of both formal (to a lesser extent) and forms of non-formal learning activities (to a lesser extent). The impact of the use of STEM education methods on learning outcomes according to the criteria proposed in the surveys is statistically significant, but this link is currently weak. This is due to the fact that the introduction of STEM education in the study of school subjects is relatively recent and it is too early to talk about the massive scale of implementation. The further development of STEM education requires the concentration of efforts of all parties involved in education for the development of appropriate infrastructure (according to the proposed model) and the training of motivated teachers. In the future, research is relevant on the inclusion in educational STEM programs of practitioners who have good STEM skills and have their own experience of going beyond traditional teaching practices.

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STEM education in the context of improving the science and mathematics literacy of pupils

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STEM education in the context of improving the science and mathematics literacy of pupils

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Abstract. The article considers the problem of STEM education in the context of improving the quality of science and mathematics literacy of pupils. The results of the monitoring study conducted by the "OsvitAnalityka" Analytical Center of Borys Grinchenko Kyiv University in cooperation with the Kyiv City Educational Agency and the Ukrainian Center for Educational Quality Assessment are presented. The state of formation of science and mathematical literacy of pupils as the ability to apply knowledge to solve practical problems for the implementation of STEM education has been established. Examples of practice-oriented integrated tasks in geography, chemistry, biology and physics that reveal the possibilities of STEM education are given. The success of the implementation of individual tasks, which involved subject integration and the use of knowledge in practice is analyzed. The most important factors influencing the quality of STEM education are highlighted: professional level of teachers, material and technical and educational-methodical support, motivation of pupils, practice-oriented content of education. As a result of the monitoring study, recommendations were prepared for general secondary education institutions for further implementation of STEM education.

1. Introduction

STEM education should play a key role in the education system, be a prerequisite for strengthening the competitiveness of the economy, human capital development and innovation. According to the Concept of Development of Natural and Mathematical Education (STEM education), "natural and mathematical education is a key direction in the development of education, part of public policy to strengthen economic competitiveness and human capital development, one of the main factors of innovative educational development, economy and the needs of society" [1]. In this context, one of the most important conditions for the implementation of such tasks of STEM education is the formation of pupils' science and mathematical literacy.

According to the methodology of the international comparative study PISA, "pupil mathematical literacy is defined as the ability to formulate, apply and interpret mathematics in a variety of contexts. This includes mathematical reasoning and the application of mathematical concepts, procedures, facts and tools to describe explain and predict phenomena. Literacy helps to understand the role of mathematics in the world, to draw informed conclusions and to make the decisions people need as creative, active and conscious citizens. Science literacy is defined as the ability of a pupil as a conscious citizen to study and solve issues related to science and scientific ideas. A scientifically literate person is ready to argue about science and technology, which requires such competencies: to explain various phenomena from a scientific point of view, to evaluate and develop research, as well as to interpret data and evidence from a scientific point of view" [2].

So, in fact, it is about the ability of pupils to solve practice-oriented tasks. In other words, use the knowledge, skills and abilities acquired at school to overcome real life difficulties and challenges. This ability is a clear understanding of the role of natural and mathematical knowledge in the modern world, the ability to explain natural and scientific phenomena, draw sound conclusions about them, understand the impact of science and technology to improve the material, intellectual and cultural environment.

At the same time, the results of the international comparative study PISA, in which Ukrainian 15-year-old pupils took part for the first time in 2018, showed alarming trends in low academic achievement in science and mathematics. In particular, 36% of our pupils did not reach the basic level in mathematical literacy (OECD average is 23.9%), in science literacy is 26.4% (OECD average is 21%) [2]. According to the results, our pupils have special problems with the application of knowledge to solve practical and complex problems. Therefore, the study of the level of development of scientific and mathematical literacy of pupils as a guarantee of quality STEM education is on time.

As N. Morze points out, "the introduction of STEM education is changing the economy as a whole, making it more innovative and competitive. According to relevant studies, attracting only 1% of the population to STEM professions can increase the country's GDP to $ 50 billion. The need for STEM specialists is growing 2 times faster than in other professions, as STEM develops the ability to research and creative activities, experimentation; ability to work in a team on joint projects, including using ICT; promotes the formation of analytical, critical and innovative thinking. In addition, it is estimated that 75% of the professions that are currently emerging and developing will require STEM skills" [3]. Theoretical and methodological problems of STEM education are the subject of research of many scientists.

Thus, S. Cheryan, S.A. Ziegler, A.K. Montoya, L. Jiang [4], M.-T. Wang, J.L. Degol [5] investigated gender differences in performance in physics, chemistry, biology, geography and mathematics. M.-B. Ibáñez, C. Delgado-Kloos [6] revealed the importance of using digital technologies, including augmented reality, for the implementation of STEM education. S. Semerikov, S. Lytvynova and M. Mintii [7] described the process of introducing a course on the development of virtual and augmented reality software for future teachers of STEM disciplines. E.J. Sintema [8] presented the impact of COVID-19 on the implementation of STEM education, in particular, analyzed the impact of the pandemic on reducing the success rate of high school pupils in national exams. L.D. English [9] revealed the prospects of STEM education, the main approaches to integration of STEM, the spread of STEM on STEAM. K. Holmes, J. Gore, M. Smith, A. Lloyd [10] presented the influence of various factors on the quality of STEM education. M. Laforce, E. Noble, C. Blackwell [11] cited the impact of Problem-based learning and pupils' interest in STEM implementing. D.G. Hoeg, J.L. Bencze [12] based on the analysis of existing educational standards and programs in the United States cited the values of STEM education. R.B. Toma, I.M. Greca [13] revealed the possibilities of integrating academic disciplines in the implementation of STEM. V. Osadchyi [14] cited the peculiarities of the use of equipment for the implementation of STEM education. N. Kushnir [15] presented open educational resources for the organization of education in the context of STEM education.

STEM education in Ukrainian schools faces a number of problems, including declining levels of teaching sciences and mathematics, non-compliance of educational content with current requirements, teaching science and mathematics to teachers of other specialties, low quality textbooks, insufficient logistics of specialized classrooms, lack in some educational institutions appropriate conditions to provide pre-professional training and specialized training of natural and mathematical subjects, etc. In turn, the lack of knowledge does not allow school leavers to choose professions related to sciences and mathematics to continue their studies. In addition, the modern labor market offers more and more competitive vacancies every year, but the weak natural and mathematical training of young people makes it difficult to select candidates for vacancies.

These factors encourage the modernization and renewal of natural and mathematical training in school in accordance with the Concept of the New Ukrainian School [16], which among the key competencies necessary for successful self-realization in society, defines innovation, mathematical competence and competence in science, and technology. We also consider important the implementation of scientific education, which according to L. Hrynevych and N. Morze is a kind of pedagogical concept, the purpose of which is to promote and study science among pupils. Thus, the overarching idea of scientific education is the introduction of new methods of teaching sciences and mathematics and the formation of a scientific style of thinking, which, in turn, is the basis of human ability to innovate [17]. The outlined requirements are in line with the "Basic Standard of General Secondary Education", which defines the requirements for compulsory learning outcomes based on the competence approach [18].

The outlined problem acquires special significance for educational institutions of Kyiv, which usually serve as a reference point for the functioning and development of the education system for other regions of the country. Therefore, the analytical center "OsvitAnalityka" of Borys Grinchenko Kyiv University in cooperation with the municipal enterprise "Educational Agency of Kyiv" and the Ukrainian Center for Educational Quality Assessment organized and conducted a study of science and mathematical literacy of 15-year-old pupils in Kyiv. In most countries, it is at this age that pupils graduate from general school and face a choice of profession.

2. The aim of research

The purpose of the study is specified in the following tasks: 1) prove the feasibility of using the integration of disciplines as a condition for the implementation of STEM education; 2) identify problems in teachers' understanding of the essence of the integration process, the introduction of an integrated course in natural sciences; 3) prepare recommendations for general secondary education institutions for further implementation of STEM education.

3. Research methods

The following methods were used in the research process: analysis of scientific and pedagogical literature on highlighting the essence of STEM education, science and mathematics literacy; analysis of online resources on this problem, methodological literature on the development of practice-oriented integrated tasks in geography, physics, chemistry and biology; study and generalization of pedagogical experience on the factors influencing the quality of STEM education; monitoring research to study pupils' ability to solve STEM tasks; methods of mathematical statistics for the presentation of research results.

Respondents of the monitoring study on the quality of natural and mathematical education of pupils of schools in Kyiv were a representative sample: 3135 pupils, 976 teachers and 195 directors of schools in Kyiv. The tools of the research included test tasks for pupils, developed by the staff of the Ukrainian Center for Educational Quality Assessment, as well as questionnaires for pupils, teachers and directors of schools. The deadline for testing and interviewing is September 28, 2021.

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This article presents some of the results of the monitoring study [19], which reveals the problem of the ability to solve practice-oriented problems as part of the formation of science and mathematical literacy of pupils to implement quality STEM education. A cluster with 6 integrated tasks was developed to demonstrate to pupils the possibilities of considering a certain phenomenon in the perspective of different disciplines (geography, chemistry, biology and physics). The cluster task was built around a cross-cutting theme. Limnological catastrophe, a rare natural phenomenon, was chosen as such a topic. The wording of the question involved consideration of the phenomenon from different angles. The subjects had to assess the importance of knowledge about the geographical laws of nature for human life, compare the hydrographic features of lakes, establish the relationship between physical quantities, analyze facts and explain them, apply theoretical knowledge in life. In addition, all test participants had to demonstrate a sufficient level of proficiency not only in science but also in mathematical literacy, as the tasks required the application of knowledge of mathematics.

4. Results and discussion

An integrated practice-oriented task was developed to determine the level of science and mathematics literacy of pupils as a guarantee of STEM education. The content of the task presents a rare natural phenomenon — Limnological catastrophe. Limnological catastrophe is a rare natural phenomenon caused by the release of carbon dioxide CO_2 from the lake water (limnology is lake science). The greatest limnological catastrophe of modern times, killing more than 1,700 people, occurred in 1986 on Lake Nios, at an altitude of 1,089 m above sea level in Cameroon. The water supersaturated with carbon dioxide rose from a depth of 150–200 meters to the surface of the lake, and the release of dissolved carbon dioxide (degassing) began. The erupted carbon dioxide spread in two streams up to 25 km from the lake, destroying all living things in its path. This condition includes two tasks in geography, two in chemistry, and one each in biology and physics. Appropriate levels of mathematical literacy are also required to solve problems. Consider the task of the test.

Task 1 (geography) If the carbon dioxide content of the two streams was lower, the consequences would not be so catastrophic. Under what conditions would the carbon dioxide erupted from the volcanic crater in which the lake formed be spread evenly in the adjacent territory within a radius of 25 km from the emission source?

A flat terrain

B temperate climate

C in windy weather

D sparse vegetation

Answer: A.

Task 2 (geography) On the tectonic map of the world, the territory of Cameroon and most of Ukraine is marked as areas of ancient platforms, within which there are faults. Why is carbon dioxide emitted by magma not saturated water in any of the 20,000 lakes in Ukraine?

A insufficient precipitation to form deep lakes

B the movement of water in freshwater lakes is impossible

C there are no lakes formed in the craters of volcanoes

D relict stagnant lakes have not been preserved

Answer: C.

Task 3 (chemistry) Carbon dioxide emitted from Lake Nios has accumulated near the earth's surface because it:

A lighter than air

B heavier than air

C is an acid oxide and reacts with water

D reacts with silica (IV) oxide in soil

Answer: B.

Task 4 (chemistry) It was found that during the Limnological catastrophe from the depths of Lake Nios erupted carbon dioxide with a volume of about 1.2 km^3 (NU). Calculate the mass (t) of this gas and indicate the closest to the correct answer among those given. For reference: $1\ km^3 = 10^{12}\ l,\ 1\ t = 10^6\ g$.

A 2400000

B $0,0024$

C 1200000

D 1200000000

Answer: A.

Task 5 (biology) Read the text: "The limnological catastrophe caused carbon dioxide CO_2 to enter the blood because gas exchange occurs due to (1) and is associated with (2) partial pressure (3)". Instead of numbers in the text you need to enter the words in the line. Please indicate the correct answer.

A 1 – active transport, 2 – low, 3 – O_2

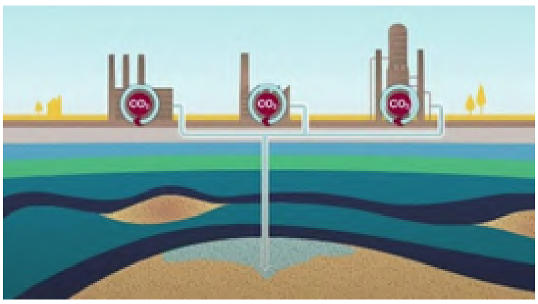
B 1 – active transport, 2 – high, 3 – CO_2

C 1 – diffusion, 2 – low, 3 – O_2

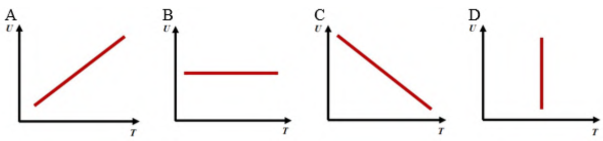
D 1 – diffusion, 2 – high, 3 – CO_2

Answer: D.

Task 6 (physics) Since the early 2000s, the technology of carbon capture and storage of man-made origin (Carbon Capture and Storage, CCS, see Figure) has been gaining popularity. According to it, this gas is buried in underground storage facilities deep underground. The



model of such a storage is a gas-filled closed vessel of constant volume. One of the arguments against the use of CCS technology is the danger of a man-made catastrophe. Which of the following graphs correctly illustrates the dependence of the internal energy U of carbon dioxide on the temperature T in the underground storage?



Answer: A.

The total number of points for the tasks is 20. According to the number of points and the complexity of the tasks there are four levels of pupils' ability to apply knowledge of sciences and mathematics to solve practical problems: primary (0–5 points), intermediate (6–10 points), sufficient (11–15 points), high (16–20 points). To describe the indicators of these levels, the approach to determining the levels of formation of natural and mathematical literacy in the PISA study is used [2]. A detailed description of the levels and indicators of pupils' ability to apply knowledge of sciences and mathematics to solve practical problems is given in the analytical report [19].

According to the results of the study, the state of formation of science and mathematical literacy of pupils as the ability to apply knowledge to solve practical problems for the implementation of STEM education:
6.3% of pupils from the total number of test participants reached a high level;
27.9% – sufficient;
42.2% – intermediate;
23.6% – primary.

According to the data, the majority of pupils (70.1%) reached the intermediate and sufficient levels, in addition, 23.6% of pupils did not reach the intermediate level. Comparing the obtained results with the normal distribution function, we note a pronounced left asymmetry, which indicates that pupils are not fully able to apply the acquired knowledge to solve practical problems and tasks for the implementation of quality STEM education (see figure 1).

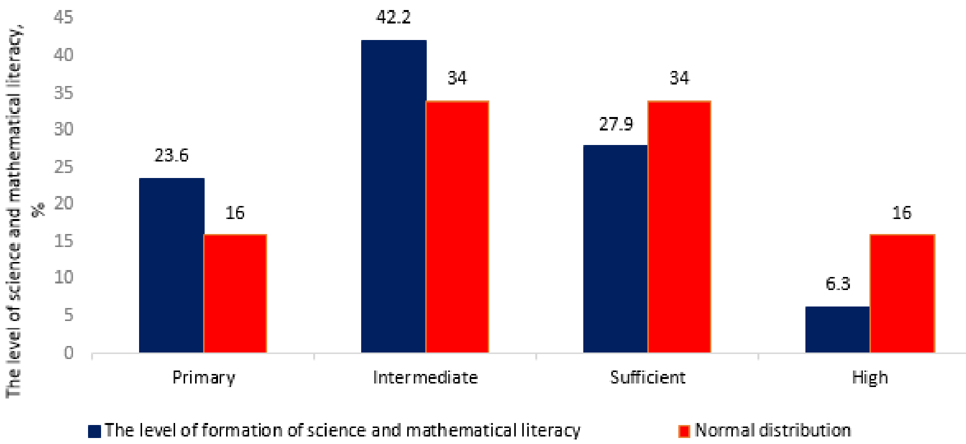


Figure 1. Comparison of the level of formation of science and mathematical literacy of pupils with the function of normal distribution.

Given that the monitoring study of the ability of Kyiv school pupils to apply knowledge of sciences and mathematics to solve practical problems was implemented for the first time, it is possible to partially evaluate its results by comparing them with the results of similar research. It should be noted that the results obtained are similar to the results of the assessment of knowledge of Ukrainian pupils in the international study of the quality of education PISA-2018. Thus, the basic (average) level of formation of science literacy was not reached by 26.4% of research participants, mathematical literacy – 36% of pupils. Only 3% of pupils became the best in the field of sciences, 5% in the field of mathematics [2]. We present the results of practice-oriented integrated tasks that demonstrate the possibilities of STEM education.

- 311 pupils (24.9% of the total) did not complete any task, only 14 pupils (1.1% of the total) completed all tasks.

- On average, 36.4% of participants gave the correct answer to each task, 41.2% – incorrect, 22.4% did not answer.

Thus, the results of practice-oriented tasks in STEM education can be assessed by the majority of respondents as quite low. In addition, the analytical report [19] states that comparing the obtained data with the finiteness of the normal distribution, we can see a pronounced left asymmetry. This indicates that pupils may not fully use the acquired knowledge to solve practical problems and tasks.

The success of each task is shown in figure 2.

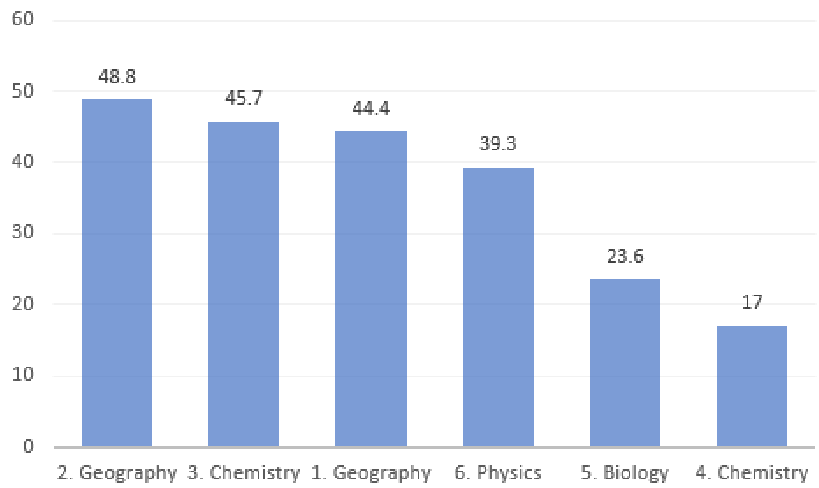


Figure 2. Percentage of pupils who gave the correct answer to individual test questions with practice-oriented integrated tasks.

As a result of the monitoring study it was established:

- Almost half of the test participants are able to assess the geographical patterns of nature of a particular area for human life; compare the hydrographic features of lakes; explain natural phenomena on the basis of chemical knowledge, the dependence of one physical quantity on another; read graphs; apply theoretical knowledge in everyday life.
- About a quarter of those tested are able to explain phenomena based on physical and biological knowledge, including the laws of biology and physics.
- The most difficult for the tested was task 4 (chemistry), it was completed by 17.0% of pupils, which indicates a rather low quality of mathematical literacy. The task tested the ability to apply mathematical methods to solve problems of chemical content, to perform certain calculations according to formulas and schemes of chemical transformation.
- The easiest task was 2 (geography), which was met by 48.8% of participants. They demonstrated the ability to establish the relationship between tectonic structure, topography and inland waters.

Analyze the success of individual tasks that involved subject integration. The pupils best coped with STEM tasks, which dealt with a natural phenomenon related to the following topics:

- “Inland waters: lakes, their types” (task 2, geography);
- “The amount of substance. Avogadro’s law. Relative density” (task 3, chemistry).

With the help of these tasks the formation is checked:

- ability to compare hydrographic features of lakes (task 2);
- ability to explain phenomena on the basis of chemical knowledge and laws (task 3, chemistry).

It was found that almost half of the test participants are able to:

- to establish relationships between tectonic structure, relief and inland waters;
- to interpret phenomena on the basis of chemical knowledge and laws;
- to explain the dependence of one physical quantity on another.

According to the results of the study, the most difficult to perform were the tasks in which the described phenomenon concerned the following topics:

- "The amount of substance. Calculation of the mass of a substance by its quantity" (task 4);
- "Breath. Human respiratory system. Gas exchange processes in the lungs and tissues" (task 5).

These tasks tested:

- ability to apply mathematical methods for solving problems of chemical content, to use certain calculations according to formulas and schemes of chemical transformation (task 4);
- ability to analyze and explain facts (task 5).

Thus, according to the results of the study, the ability of pupils to solve practice-oriented integrated tasks as a condition for the implementation of STEM learning can be assessed as quite low. Therefore, the next step of the study was to find out the factors that affect the level of science and mathematics literacy of pupils. To do this, a survey of teachers and school directors identified a number of factors, the most important of which were the following:

- professional level of a teacher;
- material and technical and educational and methodological support;
- motivation of pupils;
- practice-oriented learning content.

The study [2] also proved that these factors affect the quality of STEM education. In particular, the relationship between these factors and the number of points obtained by different pupils as a result of testing. Analyze the factors that affect the quality of STEM education in more detail. First, we asked school directors to assess the qualifications of science and mathematics teachers. It was found that the vast majority of directors claim that the qualifications of teachers of sciences and mathematics in their educational institutions are sufficient to implement quality education. Respondents rate the qualifications of teachers of mathematics, geography and biology especially highly. This is confirmed in the answers of more than 75% of directors. Slightly lower they characterize the qualifications of teachers of chemistry (72.6%) and physics (66.7%), see table 1.

Next, it was important to determine whether teachers believe that their classrooms have modern equipment and the necessary materials for the quality implementation of STEM education. It was found that 20.6% of respondents agree with this, 38.7% rather agree, 27.9% rather disagree, and 12.12% strongly disagree. It should be noted that the obtained data correlate with the information from the directors of schools: 26.7% of people are satisfied with the availability of equipment and necessary materials for high-quality teaching of natural sciences and mathematics, 35.8% are rather satisfied. The next step of the study was to determine whether pupils have sufficient interest in academic disciplines as a guarantee of STEM education (see figure 3).

Table 1. Assessment of qualifications of teachers of educational institutions.

Subject teachers	%
teachers of mathematics	75.8
teachers of geography	75.7
teachers of biology	75.3
teachers of chemistry	72.6
teachers of physics	66.7

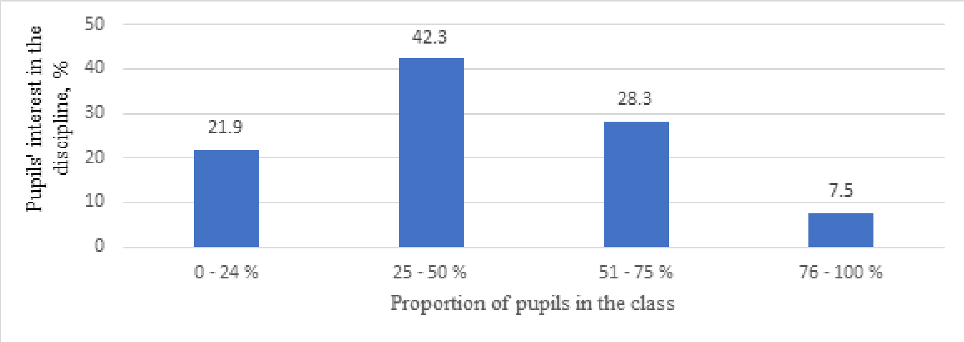


Figure 3. Pupils' interest in the discipline, %.

As a result, most teachers believe that between 25% and 50% of pupils in the class have an interest in the subjects they teach. One in three teachers (35.8%) believes that more than half of pupils are interested in its subject, one in five teachers (21.9%) say that less than a quarter of the class have a strong interest in the discipline. Fundamental in the context of our research was to establish the views of teachers on the ability of pupils to apply theoretical knowledge in practice to overcome various life challenges and problems. The obtained answers are given in figure 4.

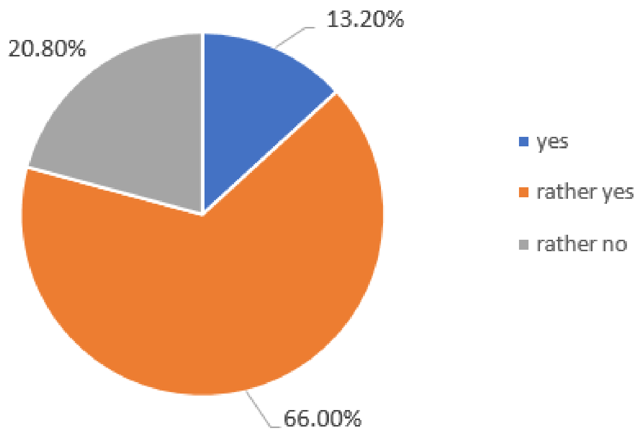


Figure 4. The ability of pupils to apply theoretical knowledge in practice.

It should be noted that only 13.2% of teachers answered yes to this question, the majority are hesitant, choosing the alternative "rather yes" (66.0%). To understand the nature of these answers, it is advisable to identify the reasons that affect the ability of pupils to qualitatively apply theoretical knowledge in practice. The responses were ranked from more important to less important (see table 2). The reasons influencing the ability of pupils to apply theoretical knowledge in practice are identified (table 2).

Table 2. Reasons for the ability to apply theoretical knowledge in practice.

Rang	Reason	The answer "strongly influenced", %
1	lack of interest in learning	61.6
2	unsystematic attendance of lessons	47.3
3	passivity of pupils in lesson	38.2
4	detachment of the content of academic disciplines from the realities of today	24.9
5	inconsistency of pupils' homework	32.2
6	advantage in teaching theory over practice	15.7

It is established that the most important reasons influencing the ability of pupils to apply theoretical knowledge in practice are the following: lack of interest in learning; unsystematic attendance of lessons; passivity of pupils in lessons. The generalization of the obtained results allowed to state that the average percentage of correct answers to integrated tasks (in geography, chemistry, biology and physics) is from 17% to 48.8%. Almost half of the test participants are able to assess the geographical patterns of nature of a particular area for human life; compare the hydrographic features of lakes; explain natural phenomena on the basis of chemical knowledge, the dependence of one physical quantity on another; read graphs; apply theoretical knowledge in everyday life. About a quarter of those tested are able to explain phenomena based on biological and physical knowledge, the laws of biology and physics. The most difficult task for the test takers was to test the ability to apply mathematical methods to solve problems of chemical content, to perform calculations according to formulas and schemes of chemical transformation. The results show that almost half of the respondents can use only scientific knowledge at the intermediate level to solve problems related to everyday life, and use subject and procedural knowledge to implement quality STEM education. Mathematical literacy is formed at an even lower level, and therefore a much smaller number of pupils can: distinguish the mathematical content of the task, given in text or graphic form; apply mathematical methods to solve problems of applied content; interpret the results of calculations in the context of the task.

5. Conclusions and prospects for further research

1. The state of formation of science and mathematical literacy of pupils as the ability to apply knowledge to solve practical problems for the implementation of STEM education: 6.3% of students from the total number of test participants reached a high level, 27.9% – sufficient, 42.2% – intermediate, 23.6% – primary. The results are similar to the results of assessing the knowledge of Ukrainian pupils in the international study of educational quality PISA-2018, where the basic (average) level of science literacy did not reach 26.4% of participants, mathematical literacy – 36% of pupils. Only 3% of pupils became the best in the field of sciences, 5% in the field of mathematics [2].

2. As a result of the monitoring study, recommendations were prepared for general secondary education institutions for further implementation of STEM education:
    - in the context of further implementation of the reform "New Ukrainian School" in accordance with the requirements of the State Standard of Basic Secondary Education for teachers of sciences and mathematics of 5-9 classes on unlocking the competence potential of mathematics and sciences, in particular to pay attention to the competence paradigm practical, life problems that are relevant to pupils and motivate them to learn;
    - development of methods of teaching sciences and mathematics, including STEM laboratories, which allow the disclosure of the competence potential of mathematics and sciences in accordance with the requirements of the State Standard of Basic Secondary Education, ensure its integration;
    - preparation of methodological materials for the implementation of extracurricular activities (excursions, observations, experiments, etc.) aimed at developing the ability to use knowledge of natural and mathematical disciplines to solve life problems;
    - development of a system for assessing the ability of pupils to apply the acquired knowledge of STEM disciplines to solve practical problems, as well as tracking individual trajectories of pupil development;
    - introduction of interactive learning technologies, strengthening the role of learning activities in the team; use of digital tools for demonstrations, simulations of experiments, popularization of group work, electives to increase the level of interest of pupils in the study of sciences and mathematics;
    - active use in the learning process of interdisciplinary practice-oriented tasks; raising the status of mathematics in the integrative approach to the implementation of STEM education. We consider it promising in further research to clarify the feasibility and prerequisites for interdisciplinary integration in the implementation of STEM education, to justify and suggest ways to address other gaps in the formation of mathematical and scientific literacy.

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Systematic analysis of digital tools to provide STEM and science education

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Systematic analysis of digital tools to provide STEM and science education

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Abstract. Recently, attention is paid to conceptual aspects of STEM or particular usage of specific tools during STEM. This paper is devoted to systemize all digital tools used during STEM classes. It is proposed to systemize all equipment into instrumental, computer simulation, and modern ones (VR, AR, and AI and 3d-modelling). It is proved the dominant role of computer simulation and modern instruments during providing STEM classes due to their simplicity and absence of necessity of expensive equipment usage. Using any of the described tools do not guaranty providing STEM, but they can be used as an element of the STEM didactic approach.

1. Introduction

The STEM approach in education is a widespread state-of-the-art teaching technology that was previously described in a lot of scientific work [1–4]. However, usage of theoretical approaches was described detailly, but only very few of studies describing some specific cases of STEM tools usage. Also, particularly describing of usage of specific tools is described in studies on the implementation of digital competence enhancement in educational institutions [5, 6]. But there are no articles related to obtaining systemic knowledge of all tools that can be used during STEM. Aspects of of STEM implementation are regulated by both, Ukrainian and worldwide strategies of development of STEM. For example, the principles declared in the New Ukrainian School concept [7, 8] may be realized through STEM. It's clear, that the USA as a STEM inventor and European commission, who saw positive results of STEM implementation, has its strategies of STEM implementation [9] and documentation [10] developed to stimulate STEM. However, STEM is developing specifically depending on the country. For example, in Ukraine, it is developed underdeveloped [11] regardless huge interest of Ukrainian scientists. It is due to a lack of practical oriented analysing of tools and methods of STEM.

Also, scientific education is gaining popularity in Ukraine. It is proved that the purpose of scientific education is to master the scientific and engineering method [1]. These methods are used in the STEM. Therefore, the concepts of scientific education and STEM are correlated.

2. Literature review

The main definitions and features of the STEM approach are outlined in the researches of Stryzhak O. [12], Polyhun N. [1] Budnik, O., [7] Savchenko, I., [13] Yakman, G. [3] and others. Based on these works, an important component of the STEM is to ensure the formation of digital skills that can be achieved through the use of special tools. In general, STEM tools can be classified into those that require the use of instruments and those that computer modelling (simulation and analysis). The first category should include digital measuring systems and other digital equipment. Digital meters, which are incapable of generating dynamic measurements, have a slightly worse potential because it is more resource-intensive and time-consuming to process information, in particular, for further displaying of information in the form of graphs and analyse this data. After all, data analysis is important for digital competence [14]. All the above tools form a STEM environment, which is a basic component of scientific education [1].

There are also theoretical and pedagogical developments dedicated to the requirements for the design of training websites and platforms that use STEM [15], for example, https://www.sciencebuddies.org, https://stemua.science/ [11].

Therefore, it seems relevant to describe and analyse STEM tools to achieve systematic knowledge about it and especially digital instruments. Using any tools or a combination of these tools is not a guarantee of providing of STEM. Because the STEM is determined by the didactics approach used to provide lesson, not by the presence or absence of specific tools in them. On the other hand, understanding these tools, which can be used in STEM, is relevant and will help to systematize these tools and improve their efficiency. Thus, the purpose of this paper is to analyse and systemise the tools that can be used for STEM implementation. Taking to account, that scientific and engineering methods may be used to achieve STEM effect of the classes, the role of measures and calculation is grown during educational process. So, the tools that provide measuring, modeling and calculations are important tools to provide STEM classes. Since scientific education involves mastering engineering and scientific methods, in fact, the article will present a classification of tools for the implementation of both, STEM and scientific education.

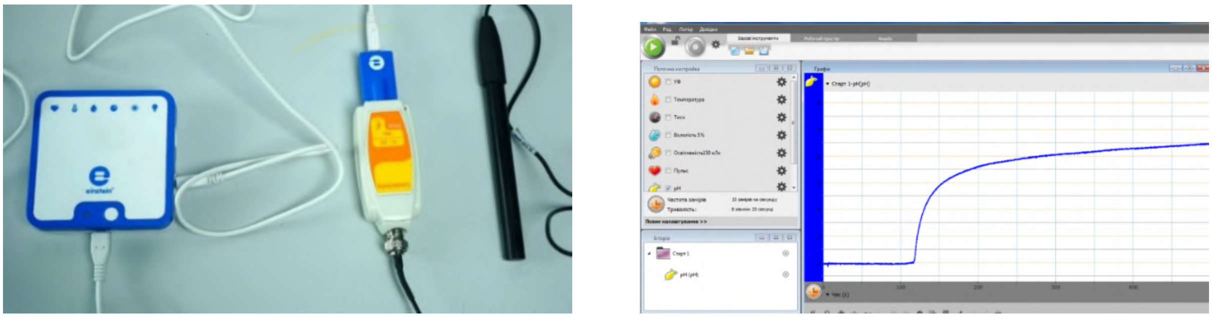
3. Methods

Specific of usage and pedagogical aspect were described for each STEM tool. To analyse the equipment that can be used to implement the STEM following information was analysed: features of use specifics of usage, role in STEM. The studies on using of specific tools were analysed and systemized. Specific cases of usage such tools were described. To provide systematization, each type of tool is described by “Features of use”, “Role in STEM and science education”, “Disadvantages” and “Examples” in form of table.

To analyze the frequency of STEM tools usage, the data on methods and scientific projects in National STEM center of Ukraine was used. Each work (both, methods and scientific projects) was evaluated by presence of each type of tools used during STEM. If the method foresees using of the STEM tool it was fixed and calculated to obtain general amount of works where such equipment was used. General amount of works that located on stemua.science and that was taken to analysis is 282 works (n=282). The results are represented in relative form based on relation of the methods where specific STEM-tool was used to general amount of work where any of tools used during STEM was used.

3.1. An instrumental component of tools used during STEM

Digital Labs is a group of advanced equipment that is capable of providing visualization of the investigated information, by conducting measurements with a certain periodicity in real-time mode. Also, digital meters can measure multiple parameters during the investigation process. Therefore, these tools can be used at the stage of the “Test Hypothesis by Doing an Experiment” during the training based on the scientific method. Today, digital labs are quite widely represented in the Ukrainian market and worldwide. The most known approaches of digital labs are produced by Phywe [16], Fourier, LabDisk, Vernier, LabQuest, TESLAlab, and others. These complexes are used quite widely [17], and there are curriculums including digital labs which are corresponding to national educational standards, [18]. An example of digital measuring systems and results of measuring are shown in figure 1.



(*a*) (*b*)

Figure 1. An example of digital measuring systems (a) and results of measuring (b).

Another type of digital equipment includes digital microscopes, sensors, and meters that have digital output to computer devices, but do not provide real-time automatic measuring. However, the functionality of such devices is rather limited, and therefore such equipment has a low potential to develop student's digital competence. However, its use requires digital skills and is still somewhat more advanced than conventional hardware. Some equipment has special embedded computer software (such as digital microscopes) that allow exploring objects more easily, and more detailly than using conventional equipment.

The smartphone has a high potential for research because it has several sensors that are capable to process data by using special software, even capable of replacing digital lab but its functionality will still be a little bit limited. Using of smartphone potential is growing significantly during using additional sensors that are very rare. Also, there is a lack of both, didactic and methodology for providing the students' studies with and without additional sensors. To conduct research and measure using mobile phone‘s sensors, it is possible to use Google Science Journal, Oscilloscope, Smart tools, Measure (by Google), Sound meter, Magnetic field meter, Lux meter, Colorimeter (although, in our opinion, it is not advisable to use Colorimeter without additional equipment) and several other applications.

There are many other approaches to use a cell phone that can use its sensors and camera as a logger to replace more professional equipment [19]. Perspective equipment is a special nozzle for the conversion of a mobile phone into a professional colorimeter. Also, promising solutions are using a mobile phone with specific sensors such as a blood group analyser, a skin pH analyser, a fluorescence analyser, chemiluminescent analyser, optical microscope, fluorescence microscope by using different cell phone's additional devices. Also, it is possible to analyse the level of chemicals in the human body such as uric acid, and determine glucose content in the blood (Google's biosensor) [19].

Of course, today there are simpler sensors that can store information for a long period, organize it, and analyse it. For example, Google Nest systems, Apple Home kit, Xiaomi Smart Home have a set of sensors that can be used for research and contain information of long-term researches. Sensors are also widely used today to investigate health, in particular, one of the largest in functionality, and one of the most developed tools is the Apple Watch, which can measure heart rate and even can constructing an electrocardiogram. Smart bands, such as the Xiaomi Mi Band, have a slightly simpler functionality but they are much cheaper and can be used to provide monitoring of the activities and heartbeat. Also, the high potential inherent for smart scales (Xiaomi mi scale), which allows to dynamically track weight changes and fat

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content, and accordingly to study the effects of certain factors on your body and can be used to build a personal healthy diet.

Another type of smart home device that can be used during STEM is plant-care devices. They allow to study specific of plant growth and therefore, to study how to care for different types of plants.

Computer simulation tools for STEM and science education

Programs used in virtual experiments and computer simulations have considerable didactic potential, especially in physics [20]. STEM software tools can be divided into search tools, informational and math modeling, and visualisation (including visual modeling). All these components are important to use during STEM-lessons. One of the simplest ways to use the software to provide STEM is using web quests [12], which suggests the use of the modeling of real-life problems and using search engines to solve them. A teacher can propose to find information to solve the problem of imaginary life situations. For example, a teacher can give a task to solve excess of the insect population and provide further discussion of the found solutions by groups. One of the progressive developments for use in the learning process to provide a research approach to STEM sessions is the "Centralized Information Web-oriented the Educational Environment" (CIWOEE) based on the cognitive IT platform Polyhedron, [12, 21] (figure 2, figure 3). Such approach has a lot advantages compare to traditional web-oriented tools, especially, during providing of science education [22, 23]. A feature of this platform is the ability to use semantic and numeric characteristics of an item of information, as well as hierarchical relationships between objects of systematization. In essence, the development is a systemise of educational guides with filtering and selection capabilities. Also, it is providing the systematisation of education material with the specialised function of filtering and ranking. CIWOEE is based on ontological educational programs and uses search to provide interoperability of educational resources. CIWOEE contains a lot of specialized STEM tools. For example, STEM-based approaches for students, systems of equipment selection, information databases (for example microorganism hierarchy), and, surely, digital curriculums were developed.

Computing applications include various calculators designed for both mobile platforms and personal computers. For example, there are some calculators designed to simplify chemistry and electro physics. Other types of calculators are programs that are capable of providing a simulation of the experiment. More developed are the systems of education, for example, there exist website stemua.science [11] that contains the works based on science and engineering methods and modelling services can be used during works providing, for example, VIREO (astronomy), and analysing ones, for example, Tracker (video analysing and measuring). There are several computer programs and web resources that can visualize the activity, such as, Corinth (chemistry, biology, geology), "Biology. Virtual lab" (in Russian), "Super quiz: Biology" (all in Microsoft store), and "Human Biodigital". Links on them are located on stemua.science. figure 4 shows a general view of the "Human Biodigital" Web Environment.

Computer modeling may be used during providing classes for students of higher educational institutions [6, 24]. There are a lot of studies related to using computer modeling in STEM [19, 25–27] and science education [28] of STEM-based physics classes, and detailed overview of the physics, modeling environments was provided by Kiv A. et al [29].

The most known and modern modelling educational environment is Go-Lab [30–32]. For example, Go-Lab is a worldwide-known system that is the part of international programs, for example, it will be implemented as modernization of STEM based environments of Ukrainian educational institutions within Erasmus+ project "Modernization of pedagogical higher education by innovative teaching instruments" (MOPED) [32–35]. Go-lab is a web-site that contains links to virtual laboratories and computer simulations. Figure 5 is shows the Go-lab website (a) and an example of computer simulation it contains (b).

Virtual Reality, Augmented Reality, and Artificial Intelligence and 3d-modeling.

Figure 2. Survey of STEM-based works selection based on the cognitive IT platform Polyhedron.

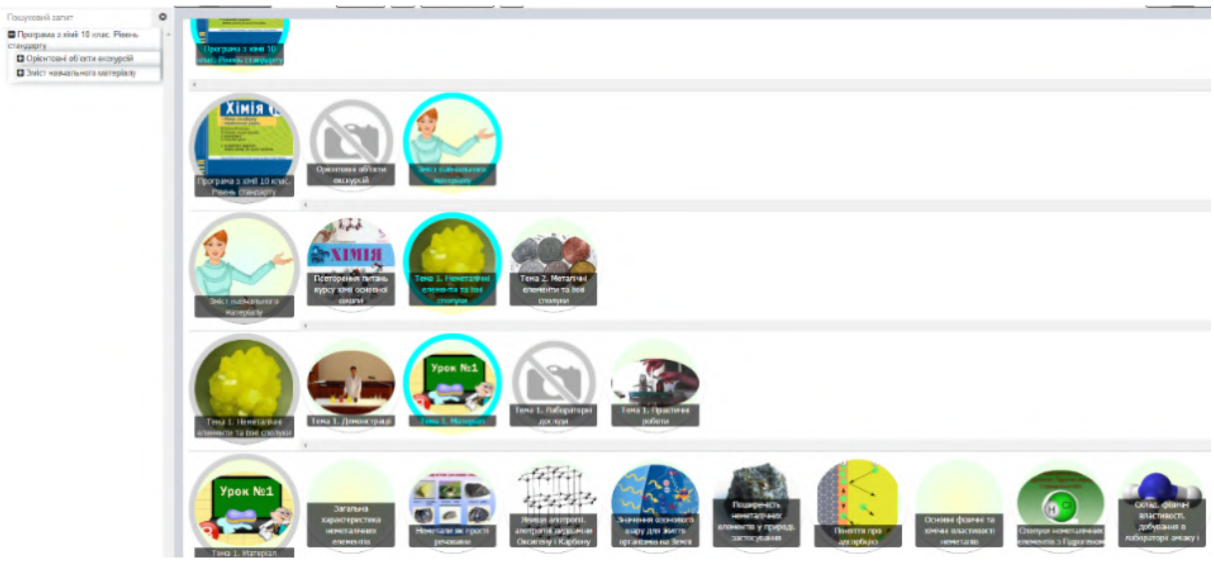


Figure 3. Digital program on the chemistry of 10 grade based on the cognitive IT platform Polyhedron.

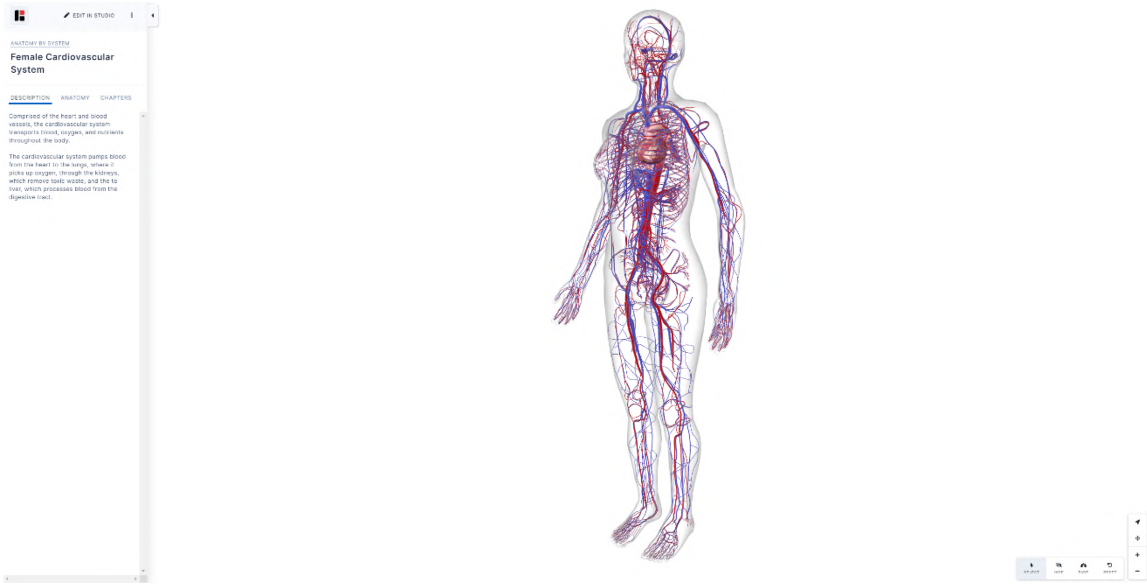
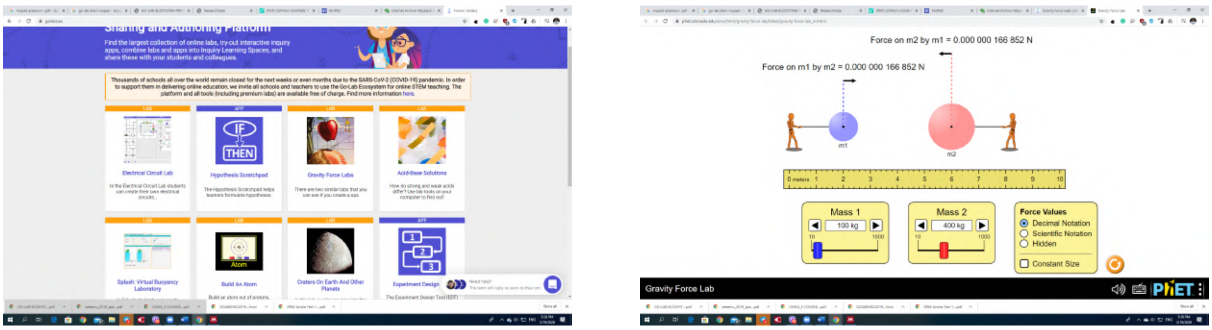


Figure 4. General view of the "Human Biodigital" Web Environment.



(*a*) (*b*)

Figure 5. General view of Go-lab website (a) and example of computer simulation it contains (b).

To visualize and motivate students to learn, a necessary component is the use of augmented and virtual reality [5, 36–39]. Due to the low level of application of augmented and virtual reality instruments in the educational process (which has more futuristic pedagogical and scientific importance), it is advisable to separate them into a separate category. Virtual reality applications allow the student to immerse in the learning process. But they are characterized by features that limit their use in the learning process, including dizziness. Virtual reality tools include mobile applications, computer applications, web services (like YouTube VR), and using special VR helmets and google glasses. There are a lot of high efiisiency spesific apporaches such as use of signaling to integrate desktop virtual reality and online learning management systems [40]

Augmented reality, which is characterized by the absence of deficiencies in virtual reality, deserves more attention. AR is a modern approach and there are some articles that declared its high implementation potential [5]. Its main advantage is the involvement of the students and increasing their motivation [36, 41]. There are quite a few applications available today to use virtual reality elements in a real-world environment, such as to render constellations (Star Chart). Also, there are applications developed by well-known scientific organizations. For example, there is an application developed by CERN (Conseil Européen pour la Recherche Nucléaire) that simulates a big bang in the real world with event chronology (Big Bang AR). This software is feasible for one-time use, a bit more interesting is software based on artificial intelligence and can be used to build STEM classes based on the scientific method. One of the most perspective applications that can provide this software is Google Lens [42] which is shown in figure 6. The application uses a phone camera and artificial networks to analyse the image and has several applications. It was identified and explored in detail the possibility of its application in the field of biology and found a positive result due to the simplicity of implementation and high accuracy on the plant analysis [43]. In our opinion, augmented reality, which is characterized by the absence of deficiencies in virtual reality, deserves more attention. There are quite a few applications available today to use virtual reality elements in a real-world environment, such as to render constellations (Star Chart).

Figure 6. Analysing the results by Google Lens.

Artificial Intelligence is used not only in augmented reality and can be quite useful for providing STEAM. For example, the Google photo application will greatly allow the use of artificial intelligence, in particular, the tool will be able to separate the photos and pictures uploaded to it by the presence of certain objects, geolocation, date, semantic characteristics, such as colour. And the latest update allows you to convert black and white images to colourful. This is a part of AI-ready software. Also, it is possible to provide programming of AI during STEM-based informatics classes. However, the last one is very hard and may be relevant only to high-Scholl students. Programming by students will not be characterized by the high quality of trained AI and usage of provided systems will be limited as it was in the case of research of Mureşan, H. and Oltean, M, [44]. However, it will be useful for the AI understanding. Besides, nowadays there are some approaches to provide education of AI to elementary school students [45–47].

Much attention is paid to 3d printing, 3d modeling and robotics in the STEM [48, 49]. And, indeed, they are tools in creating STEM classes, however, their use does not guarantee the effect of STEM classes, but only providing the correct didactic approaches in the preparation of classes can provide the effect of STEM classes.

4. Discussion

Thus, today the teacher can use a huge arsenal of equipment and software in the framework of building a STEM-lesson. The main purpose of using such equipment is to provide a number of the following features:

- Possibilities of obtaining data for research;
- Visualization;
- Increasing students' motivation for learning;
- Creativity development;
- Real-life situations modelling;
- Ensuring transdisciplinary through the ability to study objects from different perspectives.
- As was noted before, we propose to classify the equipment that can be used to apply the STEM approach into the following groups:
- Instrumental equipment
- Software approaches;
- 3D printing technology and augmented reality tools, neuro lab networks.

So, all of these instruments may be used during STEM-classes. However, all of them are characterized by some disadvantages and have several appointments that can be used under STEM see (see table table 1, table 2, table 3). In general, using both STEM-based didactics and instruments described in this article (but not only tools used during STEM themselves) will lead to a positive effect on the education process. The computer modelling instruments are very relevant during STEM due they are common, simple to use and do not need additional equipment. It has both, higher potential and a higher current level of implementation nowadays. However, it seems relevant to provide additional research to find the current level of using both computer simulation and instrumental approaches to provide STEM.

The frequency of usage tools used during STEM are used differently due to their advantages and disadvantages. Also, the frequency may differ due to regional specific. For example, Ukrainian schools were purchase Digital labs, so it was required to fill the gap in methods of their usage for Ukrainian school. As stemua.science is National virtual STEM-center, it is possible to analyse data stored in it [11]. So, an example of frequency of tools usage based on data of stemua.science is shown in figure 7.

As seen from figure 7, the most common tools are tools for calculation and modelling, digital labs and digital equipment with 37%, 31.9% and 23.% of cases of usage in works that foresees

Table 1. Instrumental tools to provide STEM.

The name of the tool	Features of use	Role in STEM- and science education	Disadvantages	Examples
Digital labs	Measuring	Gives the possibility to achieve and analyses data. Measurements and analysis of the obtained data are the basis for the application to provide educational studies, which involves learning through research.	High costs. The use of this equipment requires a certain classification of the teacher.	Phywe, Fourier, LabDisk, Vernier, LabQuest, TESLAlab
Digital equipment	Providing of static measuring. The main advantage is simplicity	Provides measuring. Gives the possibility to achieve and analyses data.	Lack of interactivity and analysing possibilities	Digital microscopes, digital thermometers, etc.
Mobile phone	Using smartphone's sensors. Main advantages are simplicity and huge spreading	Interaction of students, low-accurate measuring. Gives the possibility to achieve and analyses data.	Low-accurate, the low possibility to analyse.	Lux meter, magnetic field meter
Mobile phone with additional equipment	A very specific and not common method	May provide accurate measuring and researching	Lack of methods, hard to find additional equipment	ELISA-test, photo colorimeter, a blood group analyser, a skin pH analyser, fluorescence analyser, chemiluminescent analyser, optical microscope, and a fluorescence microscope, electrodes measuring
Smart tools	Common methods of measuring interact with personal devices	Provides systematically measuring of parameters which gives the possibility to provide long-term research	Necessary of purchasing additional equipment (however, it cheaper than Digital labs)	Google Nest systems, Apple Home kit, Xiaomi Smart Home, Apple Watch, Xiaomi Mi Band

Table 2. Software tools to provide STEM.

Searching and web-quests	Proposing using web-surmises to research	Finding information, improving creativity and involving students into the educational process	Need to be developed	Google, Cognitive IT platform Polyhedron
Centralized Information Web-oriented the Educational Environment	Proposing to use closed educational environment where students use digital programs and providing both, internal and external search to use educational researches; based on using of ontological/taxonomy approach	Gives an understanding of the educational process in general and propose to utilize the information when it necessary	Nowadays, the database does not contain all educational programs of all countries and directions. Nowadays interface is not a modern one and it recommended be used only for high-school students who mostly looking for a real research tool	The cognitive IT platform Polyhedron
Calculations and modelling	Provides possibility to visualize and create tasks of both real and unreal processes	Can be used as part of lessons to visualize or as the main instrument during practical classes	It may be hard to understand and start to use. It is necessary to search instruments teacher need	Go-lab
Visualizers	Provide visualization to real-life process in class	Can be used as an additional approach to interact with students and illustrate the materials students learns	Not provide measuring and can't be used to achieve systematic knowledge	Corinth, "Biology. Virtual lab", "Super quiz: Biology" and "Human Biodigital"

usage of tools used during STEM on stemua.science, respectively. Much rarely delivered works with using robotics and mobile phone tools. It may be due to wide dissimilation of robotics in the internet (so, it was not required to duplicate them) and due to lower level of dissemination of both, robotic and personalized cell phone tools in Ukrainian schools. Also, some tools are isn't used at all for today. As for CIWOEE, it can be used through all of the works due it provides connection of tools with educational program. Also, some tools such as AI and personalized smart tools are very perspective, but their usage is limited by current state of material base of schools and requires staff development.

Table 3. Modern tools to provide STEM.

VR-videos	Playing of interactive video using VR-equipment	Can be used to improve visualization	Limited usage learning process due to disadvantages, including possible dizziness	YouTube VR
VR-applications	Include both, games and programs VR-equipment	Can be used to improve visualization and provide interaction	Limited usage learning process due to disadvantages, including possible dizziness	VR Math, VR Education & learning 360, Tower of London interactive educational VR 3D, Google Arts & Culture
AR-applications	Provides using of AR-equipment or don't and gives the possibility to use virtual elements in a real environment or obtain information from real-life objects	Can be used as both analytical instrument and instrument to provide interaction. This effective in the study of history, geography, biology, chemistry, architecture.	Needs skills of the teacher and there is a lack of the methodology	AR VR Molecules Editor Free, AR-3D Science, Civilizations AR, Mind Map AR, Big Bang AR, AR Real Animals, AR, Human Atlas, AR-ANIMALS
Analysing AR-applications	Using a camera of the smartphone to analyse objects in the real-life	May be used as a powerful tool for providing measuring with the interaction of students into the research process	May works not best way using week smartphones due both week cameras and processor	Horizon Explorer AR, AR Ruler App, Google Lens, Dog Scanner, Star Tracker, Star Walk 2 Free, Geo Reality, Identify Anything
AI decision-making systems	Using the additional software using AI	Programming can be used during informatic classes, but AI-ready soft can be used in the testing of the students or obtaining faster results than manual analysing	Programming of AI is hard to use in general and most relevant be used only for high-school students. However, there are some cases to use even for elementary school students [46, 47, 50].	Include programming of AI and analysing (all Analysing AR-applications and some PC programs),
3d printing, 3d modelling, and robotics	Provides using of the modelling environments to created 3d-models and its further printing	Using computer instruments to provide modelling of 3d objects and its printing.	Mostly used as fact which does not give STEM-educational effect. Need to be used only with didactics of digital science education	All programs of 3d modelling and printing, and robotics (for example scratch)

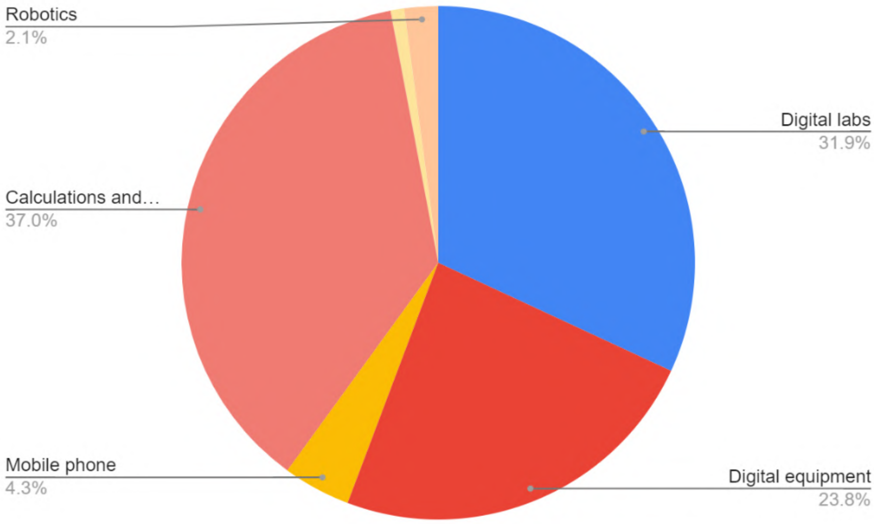


Figure 7. Distribution of tools used during STEM on methods and science projects.

5. Conclusions

Digital labs, Digital equipment, Mobile phone with additional equipment, Smart tools, Searching and web-quests, "Centralized Information Web-oriented the Educational Environment" based on the cognitive IT platform Polyhedron, Calculations and modelling, Visualizers, YouTube VR, VR-applications, AR- applications, Analysing, AR-applications, AI decision making systems, 3d printing and 3d modeling the main types of instruments that can be used to provide STEM.

All modern equipment that can be used during the application of STEM-technology is proposed to be classified into Instrumental part STEM-equipment, Applications to provide STEM s, AR, VR, AI, and 3d modeling.

The category Instrumental part STEM-equipment can be attributed to Digital labs, Digital equipment, Mobile phone, Mobile phone with additional equipment. The category Applications to provide STEM s can be attributed to Searching and web-quests, Centralized Information Web-oriented the Educational Environment of Ukraine based on the cognitive IT platform Polyhedron, Calculations, and modelling, Visualizers. The category AR, VR, AI, and 3d modelling can be attributed to VR-videos, VR-applications, AR- applications, Analysing AR-applications AI decision-making systems, 3d printing, 3d modelling, and robotics.

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Training of practicing teachers for the application of STEM education

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Training of practicing teachers for the application of STEM education

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Abstract. The modern informational society poses new challenges to the education system, and one of the ways to solve them is STEM education, which has become one of the popular learning trends. The solution of the set tasks encourages not only the growth of the economic indicators, but also the general stable development of society with a careful attitude to resources, both material and immaterial. The practitioners are the leaders in high-tech changes of the education system, that is why they are the ones who can implement the STEM approach in the most effective way. This is important because the scientific component of technology is evolving over time and, accordingly, the skills of employees that are needed are changing, too. And the STEM approach in education, in turn, is the best to meet this requirement. The professional development of practicing teachers means to update knowledge in the field and acquire new teaching methods and technologies. Thus, in addition to professional necessity, professional development of practicing teachers is of innovative importance. The proposed certificate program of advanced training aims to develop students' skills to implement STEM education in a scientifically sound and critical way; widely use interdisciplinary interaction; to introduce methods and means of STEM education in professional activity. The target audience of the program is future and practicing teachers of general and professional higher education.

1. Introduction

The development of STEM education is recognized as a priority both in the world and at the state level. The Government of Ukraine has adopted the Concept for the Development of Natural and Mathematical Education (STEM education) and developed an Action Plan for the implementation of the Concept for the Development of Natural and Mathematical Education (STEM education) until 2027 [1]. The document defines a set of measures related to the formation and development of skills in research and engineering, invention, entrepreneurship, early professional self-determination and readiness for informed choice of future profession, promotion of scientific, technical and engineering professions, dissemination of innovations in education. The provisions of the Concept for the Development of Natural and Mathematical Education (STEM education) are implemented through all types of education: formal, non-formal, informal - on the basis of online platforms, media products, STEM centers / laboratories, including virtual ones. The use of the leading principle of STEM education – integration – allows to modernize the methodological principles, content, volume of educational material of natural sciences and mathematics, technologicalization of the learning process and the formation of

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educational competencies of a qualitatively new level. The implementation of measures is directly related to teacher training. It is the competence of teachers in the field of STEM education that is the necessary condition for the large-scale implementation of STEM education. Researchers from a number of European research centers hold a similar view. Adina Nistor and her colleagues consider teacher training to be a major factor in promoting STEM education [2]. The TEMI project is given as an example [3]. The TEMI approach is built around contextual learning, encouraging teachers to use “riddles” in teaching scientific concepts. The project complements classroom training seminars, theater events and other online skills development exercises in the form of smartphone applications, videos, publications and online seminars. In addition, the European Commission has adopted a Digital Education Plan for 2021-2027 [4]. Among the planned actions is the involvement of women in STEM. According to the European Commission, such activities should increase the involvement of more participants in STEM education. Given that the majority of teachers are women, this activity is aimed at expanding the number of professionals involved in STEM education.

2. Literature review

Science, technology, engineering and mathematics have already improved many aspects of life, such as health and well-being, infrastructure, sustainable energy production, agriculture and more. In synergy with the social sciences and humanities, STEM has the potential to transform and improve people’s lives, while ensuring environmental sustainability and providing a basis for new approaches and solutions to current and future global problems. The question is to realize this potential through the training of specialists in this field. Training should begin in secondary school, and therefore an important step in this direction is the training of teachers who are able to convey the concept of STEM to students. University curricula for future teachers are adapted to the introduction of STEM education. The issue of retraining of practicing teachers, formation of their competencies in the implementation of STEM education, expansion of interdisciplinary learning skills, sustainable use of educational material based on a scientific approach and combining theoretical material with its practical content remains unresolved.

In the course of this study, open sources on the process of future teacher training and professional development of practicing teachers in the field of STEM education were analyzed. General analysis of educational trends and their impact on STEM technologies were used to identify the role and place of STEM education in the modern educational environment. An analysis of existing best practices in the training of future teachers in the field of STEM education and in-service teacher training courses was used to build a model of retraining of practicing teachers. In addition, the available data were analyzed to find relevant information to determine the conditions for the implementation of STEM education in the educational process of educational institutions. The results of the development and implementation of certified refresher courses for practicing teachers provided an opportunity to start collecting statistics for their further analysis.

STEM is a science-based concept, a learning system used by developed countries in various fields of education to develop in children and young people the skills needed for sustainable development in the 21st century. This concept arose at the request of economic stability, which is impossible without innovative growth, which requires professionals of new content. It involves a combination of different sciences, technologies, engineering and mathematical thinking. An important concept related to STEM education is interdisciplinarity. The key pedagogical problem in the development of STEM oriented curricula is the technology of integration of components, which, on the one hand, are close disciplines, and on the other – independent established ontologies: Science as a method of cognition that helps to understand the world; Technology as a way to improve a world that is sensitive to social change; Engineering as a way to create and improve devices to solve real problems; Mathematics as a way of describing the

Journal of Physics: Conference Series **2288** (2022) 012033 doi:10.1088/1742-6596/2288/1/012033

world, presenting its abstract model capable of research.

Yeping Li and Judy Anderson have presented an expanded overview of the content of research and trends in teacher training for STEM education [5]. The authors summarized and analyzed the research data, as well as discussed the need for further research and their development.

Mi Song Kim and Najmeh Keyhani explored STEM technology teacher training in non-formal education. The study analyzes the available sources on the development and progress of the informal personality of STEM teachers, recognizing its compatibility with the self-authorship framework. The results of the study emphasize the importance of teacher support initiatives that involve collaboration, mentoring and curriculum development that can help STEM teachers on their path through non-formal education [6].

The research and project activities are important means of conducting STEM education. School teachers have to implement and control these activities in the classroom. However, little is known about teachers' attitudes towards the use of research or even design projects. The study by T.E. Vossen, I. Henze, R.C.A. Rippe, J.H. Van Driel and M.J. De Vries [7] present the results of work with Dutch teachers who taught STEM, O&O (research and design) and NLT (nature, life and technology). Researchers have concluded that STEM teachers need to be further trained, especially for teachers who are starting to teach STEM subjects. As STEM teachers have different backgrounds, it is important that they are provided with sufficient time, support and professional development courses. Teacher professional development is often focused on the content of STEM projects, but in order to teach support for research and project processes, it is necessary to pay attention to the methodological support of project and research activities. In addition, teachers may need first-hand experience in researches and projects, since not all O&O and NLT teachers have necessarily done this before in their studies. Instead of existing courses in individual subjects, courses specifically aimed at integrated STEM could attract more STEM teachers and increase their willingness to attend such professional development opportunities.

The topic of augmented reality in education is quite new and little studied for STEM education. In a study by V.V. Osadchyi, N.V. Valko and L.V. Kuzmich the publication on the research topic, described the concept of augmented reality, analyzed the technologies of augmented reality, which are adapted to the teaching of natural sciences and mathematics, were analyzed. The role of STEM approach with augmented reality in the educational process is determined. An example of the use of augmented reality in the robotics project is given [8].

Nina Bencheva's article examines EU and Bulgarian policies to promote out-of-class learning, including STEM and ICT education [9]. Some best practices of extracurricular science education in Europe are identified. Teachers of the Department of Telecommunications of the University of Ruse have implemented various projects to teach students of schools in Ruse outside of formal education in the field of ICT and STEM. The article presents some of the experimental projects of teaching outside the classroom of professionals of the Department of Telecommunications.

The researchers K. Pressick-Kilborn, M. Silk and J. Martin have studied STEM and STEAM education in Australian schools [10]. They identified several problems of the implementation of STEM, including the need for professional training to equip teachers with new skills and knowledge in the development and delivery of STEM education. Two specific issues identified as critical are (a) the potential contribution of STEM education to a sustainable future and (b) the importance of STEM education for social justice, in ensuring that all children and young people have equal access to learning opportunities.

M. Dubek and C. Doyle-Jones have investigated the preparation of future teachers for the application of STEM education using the model of coeducation [11]. The research questions included: "How do candidates feel and perceive the model of co-teaching with their teachers?" and "What elements of a teacher's experience in co-teaching reflect the cognitive learning model?" This study found that teacher candidates who taught with their teachers strengthened their understanding of STEM integrated education, including STEM content and Pedagogical

Content Knowledge. Making thinking visible through cognitive learning with the help of a collaborative learning model has led future teachers to develop an understanding of STEM education in their personal teaching practice and to develop their ability to become confident and resourceful STEM teachers.

The biological threats and anti-epidemiological measures caused by COVID-19 have also made adjustments to STEM education. A. Aykan and B. Yıldırım have investigated the integration of the Lesson Study Model into distance STEM education during the COVID-19 pandemic [12]. The study focused on six points: (1) STEM education in distance learning, (2) Lesson Study, (3) lesson planning processes, (4) lesson planning problems, (5) assessment and evaluation methods, and (6) strategies; methods and techniques. The researchers concluded that the Lesson Study Model, integrated with STEM education, leads to better planning and teaching of STEM lessons. Moreover, distance learning platforms are promising ways to ensure the professional development of teachers during a pandemic.

The use of virtual and augmented reality in STEM education is no exception. S.O. Semerikov, M.M. Mintii and I.S. Mintii developed and researched the results of the course "Development of Virtual and Augmented Reality Software" for STEM teachers [13]. It is established that the course promotes the development of competencies in the design and use of innovative learning tools. A survey of the course participants on their expectations and course results is provided. Reducing hours, detailed guidelines and increasing the number of practical problems, the amount of independent work, increasing the number of classroom-related STEM subjects are called potential opportunities for the course that need to be realized.

3. Research results

3.1. Examples of implementation of STEM projects in Ukraine

The relevance and practical significance of STEM education is best demonstrated through the description of the quantity and quality of practically implemented STEM projects. It should be noted that as one of the elements of the educational process of any educational institution STEM projects are much broader than just an educational system that uses interdisciplinary links to gain relevant skills today. STEM projects should be considered in terms of the educational process as an element that helps to create a mental system of students. Since these projects have different scales, it is better to systematize the description of practical implementation not on the principle of disciplines and subjects and their interrelationships, but on the principle of "globality" of specific results.

The simplest to analyze are the STEM projects implemented within a specific subject or discipline, or even a specific topic.

The process of learning a foreign language covers almost all types of daily activities in most types of human actions, so it allows you to use a variety of STEM technologies. In particular, project technology, interactive learning technologies, case technology, mental maps, web-quest technology, etc.

Examples of tasks that can be performed in English lessons are the following:

- Lego activities that develop reading and writing skills (Alphabet - using lego to build the alphabet; Post-reading activities using lego – stick words or sentences on Lego bricks to learn the content);
- Craft-sticks – writing on a stick a new word from English that he learned in everyday life and in groups during classes, children form sentences with them;
- Elaboration in writing – students are given colored stripes of different colors with words from which to form a chain and new sentences;
- Inside my head – improving monologue speech by creating an image of a person with the help of paper and cut from magazines, newspapers, image wrappers and their subsequent

description;

- 3D House – create a model of a modern or medieval city, future city or dream city and in the process of working on projects to learn the use of English verbs in different grammatical tenses with instructions in English, of particular interest because architecture is a great example of design combination. arts, technology and engineering thinking;
- Papier-Mache Globe - in preparation for a high school debate on Traveling, children make a globe out of newspapers, choose a country, and argue why they should travel there.
- Storytelling – based on the text, students recreate events using toys in their own cartoons, create their own film about school, pet, hobbies, etc., using computer animation programs, sounding them in English. Or, they are dubbing excerpts from feature films or cartoons and overlaying subtitles in English. The process of creating paper booklets in a foreign language with the help of graphic editors.

An example of the use of STEM projects in professional pre-higher education is the involvement of project approaches in the study of the course "Computer Design" at the College of Radio Electronics (Dnipro). In particular, involving students in the software used in their studies is a creative task of developing a personal logo using AutoCad, which is then used in the drawings to confirm the authenticity of the development and authorship. Mastering the interface, the main functions of AutoCad takes place in a creative atmosphere, effortlessly, which achieves a positive attitude towards the discipline.

In the following practical works, students are invited to create their own portfolio of the designer, consisting of different types of technical drawings. The student is offered a list of tasks of varying complexity for each type of work and everyone chooses for themselves whether it will be a few simple tasks with the appropriate level of assessment, or a complex drawing that will bring a significant assessment to the developer "portfolio".

At the end of the course, students are asked to develop a model of a reproducible drawing of an electrical circuit diagram using Sprint Layout 6 – a simple and effective program for manual design and drawing of printed circuit boards for electronic devices with a high degree of complexity. In this way, students go all the way from developing a drawing to creating a board for a specific device.

The next level for analysis is the integration of different disciplines, the use of interdisciplinary links. Implementation of STEM projects in terms of integrated classes shows good practical results. In this case, subjects or disciplines can be combined in a variety of combinations, the restriction of which is only the relatedness of the issues considered in the curriculum:

- integration of geometry, physics, biology and literature on the topic "Square of figures";
- integration of algebra and physics on the topic "Function. Properties of the function";
- integration of geometry and geography on the topic "Applied Problems" for the application of material on solving triangles;
- integration of geometry and art on the theme "Quadrilaterals on the left, quadrilaterals on the right";
- integration of geometry and labor training on the topic of "Quadrilaterals";
- integration of physics with biology as a series of classes dedicated to animals – "devices" that can predict weather changes, predict various natural phenomena: earthquakes, thunderstorms, volcanic eruptions as living barometers, compasses, seismographs.

It is necessary to indicate the type of activity that is associated with in-depth study of certain material and its more detailed study – group activities (writing works of the Academy of Sciences) separately. Today STEM, STEAM, STREAM are the recognized leading trends in pedagogical practice in the world that provide for the integration of natural sciences, new technologies, research, engineering, mathematics and art, including oratory, skills to confidently and friendly conduct public discussions, to argue their scientific hypotheses, present the results of project activities. In classes on the basics of robotics and computer modeling at the Poltava Regional Academy of Sciences [14], students learn the technical and software capabilities of LEGO EV3, Arduino, learn to compose algorithms and write programs for robots, take photos and videos from quadcopters, learn modern 3D modeling technologies in the SolidWorks automated design system and print 3D models on a 3D printer. Poltava Regional Small Academy of Sciences has an official license to use the software product SolidWorks for educational purposes. The advantages of SolidWorks are versatility in achieving a certain goal at all levels of work (creation of planar and three-dimensional sketches, elements of details, conjugations in assemblies, etc.). SolidWorks also provides the ability to create design documentation, photorealistic images, video animations, engineering calculations. 3D printing capabilities, close interaction with Excel spreadsheets, teamwork on projects make SolidWorks a very effective tool for use in research and experimental activities.

Among the largest are STEM projects, the implementation of which is designed for a significant number of educational institutions in the country or is available internationally. For example, "STEM school for building modular origami" – in 2021 the program of this course was recommended by the Ministry of Education and Science of Ukraine. The course is designed for students in grades 7-9. The branches are natural, technological, mathematical, information, social (authors I.Yu. Nenashev, N.B. Godovana, T.A. Kravets, N.O. Kazachkova). The course program was developed by the authors in accordance with the State Standard of Basic and Complete General Secondary Education [15], the Concept of Development of Natural and Mathematical Education (STEM education) [16]. The novelty of this technique is that it not only solves design, mathematical and architectural problems, but also helps the student to solve research problems, forms students' scientific and critical thinking, develops creative abilities and focuses on emotional and cultural enrichment of youth.

All-Ukrainian projects include the Discover Ukraine curriculum developed in conjunction with the Kyiv-Mohyla Business School [17]. This is an educational gamified project that contains interactive instructions, teaching materials, inspiring success stories and much more for teenagers in grades 7-11 from small towns of Ukraine, in which they learn to implement their ideas and plans, changing schools, cities and all of Ukraine. In the form of games, participants work on such skills and abilities of the XXI century as team building, critical thinking, project management, communication, practice working with ideas.

Free online service "Kahoot!" allows you to create interactive educational games, quizzes, discussions, surveys, consisting of a series of questions with multiple choice answers. The service is designed for learning based on games, which makes it interesting and exciting to study any subject in any language on any device for any age. And also the service can be useful to the head and pedagogical collective of educational institution for realization of various forms of scientific, methodical and organizational work.

The game "Minecraft", which allows players to create and destroy various blocks and use objects in a three-dimensional environment, bought in 2014 by Microsoft, has become a universal learning platform – a course in programming for children. This resource (version for learning – Minecraft Education Edition) allows children to develop the competencies of the new Ukrainian school, promotes creativity, cooperation and problem solving in an exciting environment, where the only limitation is the player's imagination [18].

MozaBook software is software that diversifies school lesson tools with numerous illustrations, animations, and creative presentation features. Spectacular interactive elements and built-in applications promote skills development, facilitate experiments, and arouse students' interest. This is an indispensable tool for a STEM project.

Virtual STEM center of the Small Academy of Sciences of Ukraine – STEM laboratory

MANLab – a center of real and virtual educational research aimed at supporting and developing STEM education in Ukraine. As well as interactive simulations for science and mathematics (`https://phet.colorado.edu/`); POP-UP-figures – (paper mechanics) – develops spatial imagination, interdisciplinary connections, self-expression, mathematical, natural, digital competence; augmented reality (AR) is the complement of the physical world with digital data provided by real-time computer devices (smartphones, tablets and AR glasses) [8]; laptops, Google applications, cognitive YouTube channels, creating your own videos, dramatizations.

As an example of the use of STEM education in the educational process of students of pedagogical specialties can be considered a plan of project activities, which can be used during independent work in natural sciences and mathematics. According to the results of this work, in addition to processing the material of the discipline, the student has the opportunity to create their own case for further teaching. This case will contain indicative topics, interdisciplinary links, a list of theoretical questions from the relevant disciplines, a description of the results, the mechanics of execution, timing and resources that can be used to implement projects. That is a detailed description of the organization of project activities.

The analysis of research results, work done and our personal experience suggest that students involved in the preparation and implementation of educational projects are more motivated to research activities, as they as a result of such work "accumulates" carefully developed and meaningful theoretical material and self-made experimental material. Publication activity allows students to gain vast experience in the field of research and prepares them for independent course and final qualification works. It is also important that students in the process of studying in higher education institutions form their own portfolio of research papers, which gives an advantage when entering a master's degree and employment.

3.2. Ways to improve the skills of practicing teachers in the field of STEM

The professional activity of a teacher in the conditions of STEM education is primarily aimed at the formation and development of mental and cognitive and personal qualities of students of general secondary education, the level of which determines the possibility of their further mastery of promising specialty of STEM industry. It also involves the formation of the ability and readiness of the future graduate of general secondary education to solve complex problems, which is possible with the appropriate level of critical thinking, creativity, cognitive flexibility, teamwork and their ability to carry out research activities. All this should contribute to the formation of a holistic picture of the world, awareness of the practical value of knowledge in mathematics, physics, engineering and other subjects of STEM education, as well as the formation of "soft" skills necessary for the information society. That is why one of the most effective ways to implement STEM education in general secondary education is research activities that are implemented through the implementation of certain projects. In the course of such activities, students of general secondary education have the opportunity to independently search for information on the topic of the project, to analyze and systematize it, using a variety of information technologies. This gives them the opportunity to see and solve a problem that is essentially a research activity.

The process of teacher training in the context of the implementation of STEM education also has certain features. First, it is impossible to implement interdisciplinarity until the teacher acquires a thorough knowledge of the disciplines in which the integration takes place, so in the program of training teachers to use STEM technologies basic disciplines must precede all others, and their mastery must be given enough time. Secondly, it is the need for practical experience, in particular in the implementation of project activities. This experience is gained by the teacher during a variety of exercises, through independent work in laboratory and practical classes, in various types of repetition, as well as through the implementation of project activities during training, which encourages them to think about problems related to their learning. Due to this, teachers gain experience of teamwork and research approach to learning about the world around them, thus forming the appropriate components of the studied readiness.

Therefore, project activities should permeate the entire process of preparing teachers for the use of the STEM technologies. Third, it is very important to socialize and adapt the teacher in the professional circle, which will allow them to form an appropriate professional behavior, compare themselves with other teachers as well as provide an incentive to continue learning. Therefore, in the process of preparing teachers for the use of STEM technologies it is necessary to ensure the appropriate social interaction in the professional environment. Fourth, the effectiveness of the teacher training process depends entirely on the level of formation of its value-motivational sphere. Therefore, in the process of preparing teachers for the use of STEM technologies it is necessary to create an appropriate motivational background, stimulating their psychological readiness to learn as well as forming an active and positive attitude to technology in professional activities based on existing knowledge and experience.

3.3. Certificate training program
According to the Institute for Modernization of the Content of Education in Ukraine, the curriculum is a normative document that defines the range of basic competencies that must be mastered by those who study in a particular subject (discipline) and the system of knowledge, skills and abilities they must master [19].

The curriculum should include: an explanatory note, a list of topics of the material studied, recommendations on the number of hours for each topic, distribution of topics and time spent on the whole course, the amount of knowledge, skills and abilities in this discipline, a list of illustrations and literature for learners, guidelines and literature for learners, criteria for assessing knowledge, skills and abilities in each activity, etc.

STEM program is considered to be one that meets the main criteria: relevance and innovation of content; comprehensibility of the program implementation process (what do the learners do specifically, what conditions and equipment are necessary for effective implementation); availability of methods that allow you to use the program in any educational institution; achievement of educational and pedagogical result and availability of tools for its measurement. STEM programs are developed in the following main areas: integrated, interdisciplinary curricula; robotics and engineering; "Smart devices" of the Internet of Things; 3D modeling, etc.

The process of preparing teachers for the application of STEM education is possible during self-educational activities and through activities during refresher courses. For this purpose, the Donbas State Pedagogical University has developed and is implementing a certificate program "Implementation of STEM education in educational activities." The purpose of the certificate program is to form students' skills to implement STEM education in a scientifically sound and critical way; widely use interdisciplinary interaction; to introduce methods and means of STEM education in professional activity. The target audience of the program is future and practicing teachers of general and pre-higher education.

The developed certificate program contains five content topics. The first of the proposed topics "STEM education: the state of implementation and prospects for development" aims to provide an overview of the STEM approach and current trends for the near and long term. Historical overview of STEM education, starting from the principle of clarity, allows to distinguish the genesis of STEM development, to trace the stages of formation and influences on STEM education, from related and opposite approaches to learning. Currently, there is a sufficient regulatory framework both at the state level and at the interstate level. Mastering the regulatory framework forms the basis for the confident application of STEM. In addition to the lecture material for the course participants, an essay on "What I know about STEM" is offered.

The second proposed topic of the certificate course "Organization of STEM oriented

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educational environment" forms the theoretical basis of the STEM approach to learning. Various aspects of the STEM learning environment, inherent tools, forms and methods of learning, etc. are considered. To consolidate the studied material, it is proposed to create a structure of STEM oriented educational environment using mental maps. Self-educational activities on this topic are aimed at studying educational systems and their components, the functioning of systems in the educational environment, examples of the creation and operation of STEM oriented educational environment.

The third topic "Use of STEM equipment in research projects" considers first of all a typical list of teaching aids and equipment for classrooms and STEM laboratories. Depending on the field of education, the list of equipment may differ significantly. The Ministry of Education and Science of Ukraine approved the "Standard list of teaching aids and equipment for classrooms and STEM laboratories" [20]. It determines the requirements for teaching aids and equipment, classrooms of biology, geography, mathematics, physics, chemistry and STEM laboratories of state and municipal institutions of general secondary and vocational education. These institutions provide a complete general secondary and pre-higher education, taking into account the requirements of the latest educational technologies and teaching methods. The result of training on this topic is the acquisition of skills in the use of STEM equipment, which is possible through the practical use of equipment. Since the main form of training in the certificate course is distance, the students get acquainted mostly with the emulation of equipment or with a visual representation of the stages of use of equipment. The practical part of the study of the topic is to choose from a typical list of teaching aids and equipment needed for the educational field taught by the student and a comparative analysis of its parameters and characteristics. Self-educational activities include an overview of the capabilities of equipment and tools and study examples of their use.

The fourth topic of the program "Network resources to support students' research activities" is devoted to the implementation of STEM education through network resources. These can be virtual labs, simulators, cloud storage services and their analysis, means of visualization of the received data and creation of infographics, etc. The practical part of the study of this topic involves the creation of an electronic educational resource designed to study the topic of knowledge of students, taking the STEM approach into account.

The fifth topic is aimed at studying the methodological aspects of the implementation of STEM education in the educational process. First of all, the peculiarities of the implementation of STEM education depending on the field of knowledge are considered. Each field of knowledge has its own characteristics related to the research activities, in accordance with which the field and the specifics of the study of disciplines in this field of knowledge are built. The specifics of the industry require the definition of methodological aspects of the implementation of STEM education, which must meet the requirements of training in the field and modern global challenges to education. The practical part of the study of the topic involves a detailed development of the lesson with the preparation of all necessary materials for it. Self-educational activities involve the development of best practices in their field of knowledge with the preparation of guidelines for the implementation of STEM approach in education. The consideration of each topic is planned at levels corresponding to Bloom's taxonomy. Students learn basic knowledge of the topic, connect it with existing ones and try to apply them according to their field of knowledge. The result of the application, depending on the topic, may be new visual aids, including in digital form, the development of fragments of training sessions, tasks, including for self-educational activities that have practical significance, and so on. These stages allow us to form a basic knowledge of the topic, but this will not be enough for us. Through group work, learners begin to test their own work on their colleagues. The results of the approbation, the conducted survey, the discussion in the groups of the performed own developments are used for carrying out their efficiency. The last step is to improve your own development and make it available to the public.

4. Conclusions

The introduction of the principles of STEM education in the learning space contributes to the creation of a fundamentally new model of learning with new opportunities for teachers and students. Using an interdisciplinary approach, integration of school subjects, practical orientation, research and project activities during classes, focusing on the concept of STEM, we can build a modern, economically stable, smart and happy society with the high level of technology.

The ongoing professional training of practitioners allows to adjust the educational trends, learning technologies and scientific approaches in teaching. The proposed certificate course for practicing teachers, which, by the way, can be taken by the future teachers, allows you to adjust the knowledge of STEM approach in teaching, expand knowledge of interdisciplinary interaction in teaching, improve scientific teaching of teaching materials, learn to form a scientific approach and widely use project training.

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PAPER • **OPEN ACCESS**

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Didactic fairy tale designing as a key to proactive training of Physics and Mathematics at primary schools

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Abstract. Relevance of the selected research topic is due to its development results aiming to resolve contradictions between society's needs for personality-oriented training of Physics and Mathematics basics at comprehensive secondary school and the inadequate basic (necessary and sufficient) conditions to provide this in primary grades. Teachers also lack for a systematic and scientifically substantiated practice of immersing their students into the didactic fairytale environment. The research primarily aims to reveal the author's conceptual vision of the essence and principles of didactic fairy tale designing in order to convert it into a basic tool of Physics and Mathematics training to 1st – 4th grade pupils.

1. Introduction

First graders are in urgent need for fairy tales about mysteries of nature, in the School of Joy under the blue sky, which the Great Teacher Vasily Alexandrovich Sukhomlinsky masterfully revealed to them: "the Sun is scattering sparks. He lives high in the heavens. He has two Giant Blacksmiths and a golden anvil. Before dawn the Blacksmiths with their fiery beards go to the Sun, and he gives them two wisps of silver thread. The Blacksmiths take iron hammers; lay the silver threads on the golden anvil, and hammer away. They forge the Sun a silver garland, and silver sparks fly from the hammers and break into pieces, then fall all over the world. Sparks fall on the earth, and you can see them here. In the evening, the tired Blacksmiths go to the Sun and give him the garland. The Sun puts the garland on his golden braids and goes to his magic garden to rest." [1, p. 28].

It is a brilliant example of forming children's interest in learning about the natural world, their proactive nature-based training via a fairy tale. However, considering the age of the youngest pupils, their low adaptation to systematic intellectual work and school requirements, lack of required intellectual maturity, current background knowledge and academic experience to solve complicated problems, it is more relevant to speak about proactive training concerning not Physics, but natural sciences as this very subject is reflected in the curriculum of all elementary schools, this referring to first graders only.

The following basic components of the theoretical platform of our conceptual vision of creating the phenomenon of a didactic Physics/Mathematics-orientated fairy tale should be considered:

- the theory and methodology of teaching Physics and Mathematics at secondary schools;

- psychological foundations of the theory of proactive training as developing personality;
- theoretical principles on morphology and folk and author fairy tales' potential, their use for academic purposes;
- scientific ideas about psychology of creativity concerning two classes of creative tasks and peculiarities of solving the first-class tasks;
- the pedagogical technology of the project method.

2. Related work

The Soviet and post-Soviet periods of development of the theory and methodology of teaching Physics and Mathematics to schoolchildren, primarily in Russia, Ukraine and the Republic of Belarus, are characterized by a quite large number of studies on their problem areas.

Such authors of works on the theory and methodology of teaching Physics as A. N. Andreev, A. I. Arkhipova, P. S. Atamanchuk, T. A. Khannanova, S. Y. Kovaleva, G. G. Kordun, V. N. Maksimova, A. I. Pilipenko, V. T. Rykov, A. M. Sabo, V. V. Sagarda, O. R. Shefer, I. O. Teplytskyi, A. A. Tsokolenko, A. V. Usova, etc. consider various aspects of the problem of this process quality improvement [2–7]. While accentuating one aspect only (introduction of entertaining elements into the academic process, in particular, by means of digital technologies), one cannot but notice absence of a strategy that targets qualitative transformation of Physics training due to application of a didactic fairy tale in the suggested methodological approaches.

M. I. Burda, P. M. Erdniev, Ya. I. Grudenev, V. A. Gusev, V. M. Monakhov, Yu. M. Kolyagin, V. I. Krupich, G. I. Sarantsev, Z. I. Slepkan, A. A. Stolyar, N. A. Tarasenkova, A. Ya. Khinchin, M. B. Volovich, O. B. Yepisheva, and others make various components of theoretical principles of forming pupils' concepts and thinking modes via Mathematics resources their research areas on a retrospective basis [8–14].

Of all various relevant theoretical developments, we are particularly interested in those reflecting specific requirements of Mathematics for a pupil's personality, A. Ya. Khinchin being one of the first to reveal them. He believes that Mathematics calls for a pupil's thinking culture as the ability for full argumentation, i.e. to provide exhaustive general proof of statements, validity of analogies, achieve completeness of disjunctions, completeness and consistency of classifications. This famous mathematician and teacher associates culture of mathematical thinking with its style, variability, flexibility and creativity [15, p. 130-141].

Works by G. P. Bevz, V. G. Bevz, Ye. S. Dubinchuk, I. V. Yegorchenko, A. L. Zhokhov, M. I. Zaykin, L. S. Kapkaeva, L. V. Koval, M. G. Makarchenko, L .M. Naumova, V. V. Nikitin, O. V. Onopriyenko, M. A. Rodionov, K. A. Rupasov, S. A. Skvortsova, R. A. Uteyeva, and others are devoted to methodological aspects of forming concepts and action methods at Mathematics classes [16–19].

By no means all the results of methodological search of the listed and other authors are in conformity with the dialectical idea of the developing concept and conceptual philosophical and psychological principles of the cognition theory (traditional methods are based on classical logic). At the same time, especially in recent years, there has been a new positive trend of elaborating different versions of heuristic methods of teaching Mathematics.

The innovator-teacher S. N. Lysenkova is the first to suggest an idea of introducing small fragments of a new topic in the training process ahead of the time defined by the curriculum [20]. Practice confirms that implementation of this principle contributes to conscious perception and solid memorization of complicated training materials, accelerating formation of pupils' practical skills. The above idea is grounded upon the scientific and psychological doctrine by L. S. Vygotsky [21] about two levels of intellectual development of a personality (the level of current development at a given moment and the one defining the area of the nearest development).

Journal of Physics: Conference Series **2288** (2022) 012034 doi:10.1088/1742-6596/2288/1/012034

These principles reveal the leading role of proactive training in personality development. They are elaborated in a creative way in L. V. Zankov's principles of developing training, and, in particular, reflected in high-complexity training, in the area of the nearest development of the pupil when playing a key role in learning theoretical knowledge and including emotions in the training process [22].

The process of creating a fairy tale for a child is to rely on the psychological mechanism of his/her imagination and its components defined by L. S. Vygotsky – dissociation (division of the whole into parts), change of dissociated elements (over/understatement) and association as their combination [21].

In searching for the conceptual scheme in question, V. V. Davydov's description of the contents and structure of the training developing activity that contributes to formation of schoolchildren's empirical and theoretical thinking is of great importance [23].

Elaboration of the conceptual scheme requires studying historical roots of the fairy tale and its morphology [24, 25]. V. Ya. Propp is first and foremost to describe the fairy tale in terms of its components, reveal their relations to each other and to the whole work, introduce constants (functions of characters and sequence of functions) and variables (the number and ways of performing functions, attributes and motives of characters' actions, a language style).

Gianni Rodari's *The Grammar of Fantasy. Introduction to the Art of Making Up Stories* is considered a valuable guideline for current and future authors of fairy tales as well as teachers and parents [26]. It is a rich treasury of not only methods to boost children's imagination and fantasy through literary works and techniques to write them, but also effective methods and tools to form their interest in creativity, readiness to compose fairy tales, poems and riddles.

Our conclusion that the problem of designing didactic fairy tales belongs to the first-class creative tasks (their solution does not require intuition, it is carried out on a conscious level) is greatly influenced by the results of analysis of monographs by Ya. A. Ponomarev. His *Psychology of Creativity* and *Psychology of Creativity and Pedagogy* deal with the psychological mechanism of an individual's creative thinking [27, 28].

In planning to rely on the project method, one could not ignore the history and theory of project development (J. Dewey [29], W. H. Kilpatrick [30], J. A. Stevenson [31], J. C. Raven [32], etc.). E. S. Polat reveals these issues in a high-level mathematical way [33].

3. Conceptual scheme

1. Physics and Mathematics are not only fundamental sciences, social advance drivers, objects of aesthetic pleasure that reveal strictness and elegance of their theories, results, beauty of the methods of proof, but also the main subjects of study in the educational system. The ultimate meaning of Mathematics' and Physics' beauty and social significance implies that they have an enormous personality-development potential. Primary school teachers start revealing this potential through changing pupils' basic activities from playing (at the preschool age) to learning at primary school, while play activity serves as a reference for the leading learning role.

Younger schoolchildren's development in a harmonious unity of sensual perception, empirical and theoretical thinking is promoted by pedagogical conditions created by various kinds of creativity and aimed to acquire emotional experience of basic physical laws, formulas, abstract definitions (given in textbooks) of the essence of concepts of Physics and Mathematics. It is about the idea of their figurative presentation, first of all, via visual, literary, musical and theatrical-dramatic arts, fragments of popular science films.

2. The phenomenon of a fairy tale plays a key role in the system of pedagogically appropriate products of literary (folk and author's) creative works. It is not only the first among others, but also the most vital for children's development in an existential context. Motivation for

the choice of prioritizing this phenomenon at primary school is essential for a conceptual vision of its potential as a key educational value and tool.

It is through a fairy tale that parents exercise their psychological and pedagogical support of their child's primary perception of the world, their son's or daughter's entry into his/her spiritual and moral space. It is very close to younger schoolchildren who already have experience of happy living in fairy tales and realizing their natural needs in fantasy, their value and semantic moral charge, high emotional and imaginative potential.

However, the main thing is that at the preschool age, fairy tales bring children even closer to their mother: when jointly immersed in a fairy tale plot, they always feel love of this very dear person, who can instantly answer some emerging questions and ask important ones. *The tale becomes associated with children's need for love.* As a result, at the level of consciousness and subconsciousness, their memory maintains warmth of love, which comes from the mother when revealing secrets of products of fairy tale creation (love radiates from her speech, facial expressions, gestures, happy laughter, kisses, and touches).

3. Emergence of didactic fairy tales of various functionalities designed for academic purposes to be used at primary and secondary schools of all levels as well as at higher educational institutions has become the peak of fairy tale evolution.

An author's didactic fairy tale is a literary work, either prose or poetry, which uses a fictitious plot (heroic, magic, natural and domestic) to reveal individual phenomena and specific laws of nature, elements of chemistry, biology and mathematics (calculus, elementary algebra, geometry, the theory of elementary functions and elements of analysis).

The author's spiritual and didactic fairy tale is a carrier of systemic values including higher human values and those of the main content of Physics, Mathematics, Chemistry, Biology and other subjects at comprehensive secondary school primarily in the conceptual and categorical dimension as it possesses appropriate fictional figurative (sometimes with a radically fantastic bias) tools to present them to pupils.

4. Spiritually didactic and purely didactic fairy tales are not guests, but full-fledged and basic tools of elementary school education, which should be fixed in the curricula in the form of a special integrative proactive course *Fairy Tale Lessons* (another title is also possible). It is about anticipating the timing of pupils' mastery of basic concepts of those sciences, the full study of which is planned at high school. The most important content area of this course is physical and mathematical.
5. The psychological mechanism of proactive training of Physics and Mathematics by fairy-tale tools includes the need-motivational and axio-acmeological components.

Pupils' emotional perception of the content of a didactic fairy tale, their readiness to reproduce physical and mathematical concepts as visual images are results of vivid reflection of these values in the literary work. It contributes to the psychological effect of infecting primary pupils emotionally, experiencing them as self-valuable, activating the mental mechanism of sense-making. All this is a signal to a teacher as a creator of conditions for pupils' development to be aware of the need to shift first to empirical and, later on, to theoretical types of thinking.

Physics and Mathematics proactive training at elementary school using a fairy tale is a potential source of a pupil's personal acmeological development. This process has two vectors of orientation:

1) the axiological vector aimed at increasing the value-based potential of the academic subject's personal axio-sphere and its enrichment with new developmentally strategic axiological formations;

2) the synergetic vector focused on pupils' awareness of the need to improve their own not quite structured life activity, self-organization of their training, in particular, the physical and mathematical one, and existence as a mature person.

6. Designing a didactic fairy tale of physical and mathematical orientation is a process of creating a pedagogical micro-model of figurative reproduction of a particular situation to manifest some general patterns of natural phenomena, features of properties and relationships of mathematical object elements as system entities based on attributing the magic status of communication subjects to material and mathematical objects, and introducing unreal fantastic characters in the plot.

In the systemic and technological aspect, didactic fairy tale designing looks like defining the architecture of a target pedagogical micro-model which covers scientifically grounded theses regarding explanation of literary-artistic and other solutions to a given academic problem. The model also includes its structural components and their functions, an integrity of methods, means and rules of interaction between them, some basic principles of the heuristic action aimed at creating this system-based work.

In algorithmic and operational terms, the main micro-stages of this process technology that reveal systemic features include:

- clarifying and realizing initial physical or mathematical data of the design problem set;
- choosing the most appropriate type of a fairy tale to be developed (either a transformational-heuristic on the basis of a known fairy tale or a holistic-innovative one);
- extracting and formulating a problem, ways and methods of ensuring the interrelation of scientific knowledge with figurative means of its demonstration;
- generating the main idea;
- finding optimal principles of building a heuristic literary and pedagogical search depending on the type of a tale created;
- developing the plot of the fictional part of the academic micro-model being guided by these principles and activating imagination and fantasy;
- synthesizing the structure (its scientific physical-mathematical and fictional imaginative-fantastical components);
- assessing and correcting the obtained synthetic model representation according to the criterion of its correspondence to the creative idea.

The main requirements for arranging the process of the didactic fairy tale design for proactive Physics and Mathematics training to primary schoolchildren are reflected in the following *principles*:

1) the principle of integrity of revealing physical and mathematical potential of folk and author's fairy tales to creatively transform them into didactic ones (the transformational-heuristic type);
2) the principle of creative freedom in changing plot elements of folk and author's tales (prologue, plot, collision, intrigue, peripeteia, climax, denouement, etc.), their plot schemes, expanding or choosing new characters in the main plot development of the narrative theme;
3) the principle of successive conditioning when selecting the scientific physical and mathematical content to create a holistic and innovative didactic fairy tale via proactive training considering pupils' age;
4) the principle of personality-development acmeological orientation of designing a holistic-innovative didactic fairy tale based on elements of scientific knowledge in the field of Physics and Mathematics;

5) the principle of strict subordination of story and plot fiction by the creator of a didactic fairy tale of all types (transformative-heuristic and holistic-innovative) to the strategy of proactive formation of pupils' knowledge of Physics and Mathematics basics.

4. Specific features and examples of practical implementation of the conceptual framework

Designing fairy tales of the first type has some peculiarities. It is up to their creator to choose one of the three options in this process guided by the principle of creative freedom:

1) in a new didactic work of the fairy tale genre, main characters of folk or author's basic tales known to children remain the same, only some elements of their plot change;
2) in the plot development of the narrative theme in basic fairy tales, either completely new characters act or the roles of old and new characters are combined;
3) the story line and the plot of folk or author's fairy tales as a special integrity become a means for pupils to discover some new elements of the academic content in proactive training in the system of their problem-search methodological presentation based on fairy tale motives (elements of the plot and the story line of the basic fairy tale become a platform for methodological development of a special lesson to disclose its educational potential).

4.1. Illustration of the first option

When designing, the first two action principles and the principle of strict subordination of the plot and story fiction to the strategy of proactive knowledge formation of Physics basics among third-graders are chosen as key ones. This plot element is changed in Charles Perrault's fairy tale *Little Red Riding Hood* as the denouement, in which Grandmother and her granddaughter remain alive, sit side by side, drink tea and remember the evil wolf. This fairy tale created by the author of the article is called *How Little Red Riding Hood and Grandma talked about the wolf's power*. Here is the extract from the fairy tale:

"...Little Red Riding Hood and Grandma drank some tea and started talking.

"The villain has tricked us, Granddaughter," sighed Grandma. "That's a shame. If you hadn't shown him where my house was, who knows how it would have turned out?"

"I'm sorry, darling," the girl almost cried. "No more shall I be deceived by tricky speeches of any deceitful and terrible beast."

Grandma looked approvingly at her granddaughter and said, "All right, Red Riding Hood. Be smarter from now on. And I, the old me, failed when I told the wolf how to open the door. He tricked me, too."

Little Red Riding Hood hesitated, looked at the door, and then asked, "Grandma, did nothing prevent the villain from opening your big thick door?"

"What are the locks for?" she asked. "They say different things about how I advised the beast to release the door from the locks. Whether the wolf pressed the latch or pulled the rope, but the result was the same: the latch bounced."

"And the door just opened, didn't it?"

"No, it didn't. It opens to the outside. The grey cheater must have pulled the door towards him. There's also a handle. And the wolf is a pretty strong animal. His strength is hidden in his muscles."

Little Red Riding Hood agreed:

"Yeah, my mom told me that both humans and animals have muscles. Here are my muscles, look how big they are! I tense muscles in my arm, and power builds up in them!"

"You are like a sparrow!" Grandma laughed and put Granddaughter's hand down. "The moment the wolf pulled the door handle toward him, his paw muscles contracted like the muscles

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in your arm do. But here's the main thing: the beast's muscles brought both the wolf himself to the door and the door to the wolf with equal force."

"I don't quite understand, Grandma."

"In fact, there was not just one muscular force acting between the wolf and the door, but two forces," the old woman clarified. "The wolf applied the first one to the door, and the second one – from outside – was applied to his own body. And those forces were equal."

"So the door kept the wolf out, didn't it?"

Grandma took the girl by her hand, led her to the front door and said, "Look! We are standing in the wolf's place when he pulled the door open. His force was directed towards the yard that could be seen behind us. The force of the door, on the other hand, was directed in the opposite direction – towards my room."

"What if one would have to push the door instead of pulling it?"

"The wolf would have had to push it towards my room. Still, the force with which he would have done so would have caused a counteracting and equal force to his own. Only those forces would have pushed the beast and the door apart instead of bringing them closer together."

Little Red Riding Hood pulled the door open and suddenly turned to Grandmother.

"Some kind of the wolf's magical force. It turns out to be dual."

The old woman smiled and said, "In nature, all forces are dual. Whether an ant pulls a straw, or two rocks hit each other in the mountains. They are all examples of dual forces."

So, Red Riding Hood tried to conclude, "If a force acts on something (and not necessarily on a door!), there is always another force."

"This other force is equal to the first one and is necessarily opposite to it," Grandma concluded. "It's the law of nature."

"And yet it's a pity", Red Riding Hood remarked, "that this law didn't prevent the wolf from entering your home [34, p. 247–252]."

Little Red Riding Hood, Grandma and the wolf are the main characters of Charles Perrault's fairy tale. They are also dealt with in a didactic story based on the original one to illustrate the effect of Newton's third law. In revealing the didactic potential of the famous French storyteller's work, the fact of the wolf's *interaction* with the closed (and then opened) door of Grandma's house turns out to be the key one.

4.2. Illustration of the second option

When designing, the key principles include the first two action ones and that of strict subordination of the plot fiction to the strategy of proactive formation of third-graders' knowledge of Physics basics. We will focus on introducing third-graders to the secrets of solid-state fusion, formation of their understanding of the crystal lattice, the atom and forces of interatomic interaction based on the content of the folk tale *The Fox, the Hare and the Rooster*. Actually, the fact that in spring the fox's ice hut melted, and the hare's did not, is the most significant pivot for creating a new project. The old narrative theme with the red-haired rascal, the Hare chased out of his house, his rescuer Rooster are not mentioned anymore in Grandpa Didactic's fairy tale *How the Ice Melts, or the Story of the Ice Hut that can be Read in the Dwarves' Diaries.*

"... It was winter, when there were many, many days before spring, on the icy roof of the fox's hut the two dwarves, the Degree-Teller and the Heat-Teller, got acquainted and immediately felt a deep sympathy for each other. They quickly became friends bound by a common interest – they both loved to count all things related to the ice hut. How weird they were! They were not interested in the Fox's things at all. Even the chickens (the redhead did not forget to eat them even at home) did not attract the dwarves' attention. The Heat-Teller constantly counted the amount of heat that the Sun brought to melt the ice, and the Degree-Teller considered his duty to establish the degree of the ice heated by the Sun's rays. Just like a thermometer measures the temperature of a sick person, he measured the temperature of the roof.

Every evening the friends used to share their recent measurements with each other. Together they wondered, got upset when the temperature and heat stopped rising for a while, and scolded bad weather.

At the beginning of spring, both dwarves could not hide their joy. Every day the amount of heat received by the ice from the sun was increasing, as well as its temperature, which the Degree-Teller carefully measured. The dwarves were very busy. But one evening the Heat-Teller didn't recognize his friend. The pale and confused Degree-Teller complained that for the second day the temperature of the ice was not increasing, but remained equal to zero.

"Look at the ice," said Degree-Teller excitedly, "It looks completely different. Water has appeared in many places, the roof of the hut is leaking. The temperature is not rising and the ice is changing its shape gradually. Soon it will change from a solid to liquid and will have no shape or volume at all, it will become liquid. It is terrible, I think the ice has got sick; at zero degree, it just melts. Do you, heat lover, know why the ice used to be healthy even in the sun?"

"All I know," his friend replied, "is that the Sun wants to melt the ice. But he failed to do it right away. In the beginning, the Sun had to send so much thermal energy so beloved by me to the roof of the hut that the ice could heat up to its melting point, or, as we used to say, thawing (for ice it is zero degree). Both yesterday and today he has managed to heat the ice to that temperature, but the ice is still there. Why do you think that happens?"

"Degree-Teller, are you saying that the Sun will need to release more thermal energy to melt the ice?"

"Of course, my friend, and without boasting, I am going to count it. But if tomorrow the Sun hides behind clouds and it gets colder, the Fox's hut will be temporarily saved. You are right, the Sun has done only half of his job, and without additional solar heat the ice will not melt. Yet, I really have no idea what to melt or to thaw means."

"I'm going to disclose this mystery anyway," the Degree-Teller declared. "Tomorrow, when the ice temperature on my thermometer reaches zero, I'll have nothing to do again. Then when it's light enough, I will try to get into the inner sanctum of ice, as well as any solid body, in its Crystal Lattice."

The Degree-Teller used to study at the dwarves' school once and heard that all solid bodies, like houses made of stones, were built of bricks-crystals, i.e., they had a crystalline structure. But the word *crystalline* was so long and difficult for him, and the word *lattice* brought back such terrible memories of his days once spent in the dungeon, that the dwarf decided to warn his friend, "Degree-Teller, be careful! You can be a wizard, but try not to stay behind that lattice forever."

The next day as soon as the temperature of the Fox's hut reached zero, the Degree-Teller pronounced three times the secret incantation heard from his grandmother and he was turned into a dwarf invisible even under a microscope. Charmed by the wave of sunlight, he lost consciousness for a few seconds and only woke up in one of the crystals inside his lattice. While his eyes were getting used to the darkness, he sang a song to banish his fear, "When the Sun melts the Fox's icy hut with the light, the clever dwarf will understand everything in this crystal lattice."

The Degree-Teller was about to repeat this verse, when suddenly he heard someone crying.

"Don't cry. I'm not going to hurt you. Let's get acquainted. I am the Degree-Teller," said the dwarf. Only then above his head, to his left and right, he clearly saw many balls arranged in a certain order and at the same distances from each other.

"My brothers and I are called Atoms," the boldest, closest ball introduced himself to the dwarf. - We, Oxygen and Hydrogen Atoms, are tiny particles that make up the ice crystal."

After looking closely at the Atoms and talking to them, the dwarf learned that the Balls-

Atoms are bound together by a great force, named **the Force of Interatomic Interaction**. It is what holds the Atoms together in this amazing order. "I'm going to sketch this Ice Crystal Lattice for the Degree-Teller," he thought. "My friend will be very surprised to see that image."

While the dwarf was drawing the balls in his notebook, trying to keep the distances between them equal, the Atom Brothers' cries intensified.

"What is wrong with you? Who has hurt you?" said the Degree-Teller to his good friend, the Oxygen Atom.

"Don't you feel it has become a lot warmer in the lattice?" the little man said in surprise. "We are crying because we feel the amount of internal energy of the whole crystal increasing. And the more heat the Sun sends, of which you sang so beautifully, the weaker the forces of inter-atomic interaction that bind us are, and the closer the end of our brotherhood is."

Suddenly the Oxygen Atom, startled by something, almost screamed:

"Degree-Teller, look! My Brother Atoms are moving away from me and I can't hold them back. How terrible, we're breaking up, our crystal has melted!"

"Wow, it's really hot," the dwarf remarked belatedly and habitually looked at the scale of his thermometer. "And my thermometer still reads zero! I wish the Degree-Teller were here to tell me exactly how much more heat the Sun has brought in since I *dived* into the lattice," the tireless researcher reasoned. "Oh, where is it? Where are the Crystal Atoms?"

Alas, the Atoms that surrounded him and made up the strict lattice of the Crystal were no longer there. And only after looking through binoculars, which always helped him out if necessary, the Dwarf found his new friends-Atoms moving at rather large distances from each other without any order.

Remembering the words of one of them about the forces of interconnection between the Atoms-Brothers in the lattice, the Degree-Teller exclaimed, "So this is what happens when these forces of interconnection between atoms are weakened by the action of solar heat: another substance, water, is formed from a solid crystal of ice!" In a few seconds he was already telling everything to his friend, the Heat-Teller [34, pp. 76-84].

4.3. Illustration of the third option

In designing the methodological development of a fairy tale, the fairytale-based lesson *The main secret of "Turnip"*, the first two principles of action and the principle of strict subordination of the plot fiction to the strategy of proactive formation of second-graders' knowledge of Mathematics basics are chosen as key ones. In this example, the folk fairy tale *Turnip* itself becomes didactic through problem tasks and questions to pupils based on its motives. *Turnip* has a great potential for pupils for learning the essence of *consistency.* It is revealed by Grandpa Didactic, who actually conducts a lesson of developmental character on a holistic platform of this folk tale potential.

"The search for the secrets of the folk tale the *Giant Turnip*", Didactic persuaded, "is the most worthy work for inquiring minds. Just don't forget that the weak-willed and alone cannot cope with *the Turnip.* It is not without reason that the tale itself underlines: *"A turnip cannot be dealt with by the weak. The granddaughter, the dog and the cat give Grandpa and Grandma their helping hands and paws, but some more help is needed!"*

And now, attentive girls and boys, tell me how many characters there are in *The Turnip.* Do they constitute a set?

Let us call this large set *Fairy Tale Characters.* We could have assigned a special number (from one to six) to each character, but we have not yet figured out the secret by which these characters are lined up one after another in the vegetable garden.

Now, please remind me, who's grabbing whom? The answer is as follows: *"Grandpa is grabbing the turnip, Grandma is grabbing Grandpa, the granddaughter is grabbing Grandma, the dog is grabbing the granddaughter, the cat is grabbing the dog, the mouse is grabbing the cat".*

Task 1. I wonder why Grandma grabbed Grandpa and not the mouse? Ah, the mouse wasn't there when Grandma came running to the garden. *Well done! You've figured out the secret, or as they say, the law, by which we will now assign numbers to all of our six characters. Grandpa who is the first to pick out the turnip becomes number one, Grandma is the second and she becomes number two. And will you assign the numbers to the rest of the characters?*

So, the cat receives number five and the mouse – number six as it is the very last to come. We do everything according to the law specified in the tale: the law takes into account the order the characters (members of the set) arrive at the vegetable garden. And it is considered that if the law by which a number is assigned to a particular member of the set, the sequence is specified. We have a given sequence of the characters of the fairy tale appearing in the vegetable garden: Grandpa, Grandma, the granddaughter, the dog, the cat, and the mouse. We can say that they come to the vegetable garden in the following sequence: 1, 2, 3, 4, 5, 6. Do you remember who is number four? And number five?

Numerical sequences, or just sequences of numbers, can be different. This usually happens when the law by which certain numbers and members of a set are *friends* with each other changes. But it also happens that the law has not changed, and the sequence takes a different form. So, at the end of the tale it is said, *"The cat is calling the mouse. The mouse is grabbing the cat, the cat is grabbing the dog, the dog is grabbing the granddaughter, the granddaughter is grabbing Grandma, Grandma is grabbing Grandpa, Grandpa is grabbing the turnip and they are all pulling and pulling and finally out is the turnip."*

Good for them! But it turns out that the sequence of the characters' arrival at the vegetable garden is the opposite at the end of the tale. Who comes to the vegetable garden last (the mouse) is the first in the final phase and vice versa (Grandpa is the last).

Task 2. *Try to write down a new number sequence so that it corresponds to the last indicated phrase of the tale. Remember that the law remains the same, and don't forget what numbers we have assigned to the characters in the tale.*

Indeed, at the end of the tale, this very numerical sequence is classified: 6, 5, 4, 3, 2, 1.

Task 3. *You have done a good job. Still, I wish you could find another sequence in the tale. And you will definitely cope with the new task! But first, list all the people pulling the turnip in the tale.*

They are Grandpa, Grandma and the granddaughter who are part of the set *People*.

Now, tell me which characters in *The Turnip* belong to the set of: a) pets; b) rodents?

How many members are there in each of the three sets – *People*, *Pets*, *Rodents*? There are three people, two pets, and one rodent in the tale. The mouse makes a singular set.

Is the number of the members in these sets the same? Is it increasing? No, on the contrary, it is decreasing: there were three members (Grandpa, Grandma, and the granddaughter), and now there are two (the dog and the cat); there were two, and now there is only one member left – the mouse.

How much fewer members are there in the set *Pets* compared to the set *People*? How much fewer members are there in the third set (rodents) compared to the second set *Pets*?

Starting from the second set, the sets are reduced by one. Here we have disclosed a new law, according to which another sequence is set in the fairy tale – the sequence of three sets. Each of the numbers – 3, 2, 1 – corresponds to the number of members from the sets *People* (3), *Pets* (2), *Rodents* (1), but so that, starting from the second set, each set contains fewer by one members than in the previous one.

The new sequence has only three numbers – 3, 2, 1.

It turns out that a sequence can be made up of sets, numbers, shapes, etc. The main thing is to discover the law of its creation [34, pp. 168–174].

The most striking examples of holistic and innovative didactic fairy tales of mathematical and physical orientation created by the author of the article without relying on well-known fairy tales are *On the Beauty Parade of the Queen of Symmetry* and *Who is the Mother of the Ball Lightning?* [35]. Each of these tales is rather long, and therefore they are not reproduced here.

Figure 1. *Grandpa Didactic's Tales* [34].

Figure 2. *On the Beauty Parade of the Queen of Symmetry: Clever Tales for the Inquisitive* [35].

5. Basic methods and techniques of creating holistic-innovative didactic fairy tales

The totality of relevant methods and techniques answers the main question – how to create a new didactic work in the form of a fairy tale? First, the choice of tactics of this process depends on the selected physical or mathematical content of the future didactic tale in accordance with goals of proactive training of these subjects and pupils' age (the third principle of the fairy tale design). Secondly, the designer should not forget to make his/her development (goals, the content, tools and methods of its design) personality-oriented (the fourth principle) including its subordination to the strategy of proactive Physics and Mathematics training (the fifth principle).

Hence, the method of integrity of the strategy and tactics of the didactic fairy tale design is the leading one. The strategy consists in turning it into a tool of developing pupils' cognition, their acmeological development as a personality, and tactics when choosing the scientific content, methods and fairy tale tools adequate to this strategy.

The best case scenario is when a primary school teacher is a fairy tale designer. At the stage of selecting scientific knowledge, he/she needs to create a didactic fairy tale. Here the following technique is of primary importance: to identify him/herself either with a mathematician or a physicist, and then – with a storyteller. The teacher should possess relevant knowledge and skills to match the main idea of synthesizing scientific knowledge and fairy tale tools of its literary representation.

Reflection as comprehension and reconsideration of experience stereotypes is essential in the system of the main methods of designing a fairy tale as a creative task. Reflexive extraction and formulation of the problem, reflexive formation of the idea of its solution are among the most efficient techniques of this method. Reflecting from the viewpoint of a child is a special type of meditation. The teacher-designer simply needs to put him/herself in the place of a little discoverer, imagine how to emotionally perceive and analyze the problem situation suggested by the teacher, anticipate the course of their logical thinking when solving it. When planning creative tasks in mathematical and physical fairy tales, the teacher puts forward hypotheses for pupils and mentally designs probable options of their verification for each of them.

To make a didactic fairy tale appealing to children when telling them about complex things in a way that is accessible to them and simple, the teacher's method of identification with a pupil of a particular age also plays the key role in this process. Here the following techniques can be helpful: reproduction of images of the teacher's own childhood, reminiscences of his/her first steps in mastering a certain training material; comparison of images "He/she is a child of a particular age" and "I am a child"; transformation of the image "I am a child" into the image "He/she is a child of a particular age" on the basis of the author's temporary abandonment of certain features of the image "I am a child"; mental reproduction of the situation of acquaintance of a pupil of a particular age with the content of a fairy tale [34, p. 311–312].

It is clear that development of holistic and innovative fairy tale didactic works applicable to teaching Mathematics, Natural Sciences and special fairy tales lessons is certainly not limited to the above methods and techniques. Every teacher has his/her own creative tools and there are unique techniques of creating a literary and didactic product developed over time, conditioned by hereditary and axiological factors.

Some years ago, the Head of the Chief Department of Education and Science of Donetsk region started a pilot project of teaching the subject *Fairy Tale Lessons* (called Fairy Tale-Based Creative Lessons in some schools). The course targeted primary pupils and was based on the specific programme. In this experiment, the book *Grandpa Didactic's Tales* acted as a reference teaching guideline. The author's design of didactic fairy tales reflected in that and other books as a creative task for the first grade was carried out mainly according to the conceptual scheme disclosed in this article.

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Smart systems of open science in teachers' education

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Abstract. The project announced by the authors is focused on the smart systems of open science, the issues of elaboration of methodological, methodic, and organizational support for the use of these emerging ICT in teaching and research, increasing the level of ICT competence of educators, including teachers. Given the significant pedagogical potential and novelty of existing approaches to the use of smart learning systems meaning first of all the cloud-based adaptive open science systems, their design and use in educational institutions, these issues still need theoretical and experimental research, refinement of approaches, models, methods and techniques, possible ways of implementation. In the process of studying leading experience, the following advantages of using the cloud-based services for teachers' training were identified: resource savings, access mobility, elasticity, and others. The cloud-based methodological system for educational personnel training at different levels was proposed and considered: for the training of students for the Master level for educational sciences; for the in-service teachers' training. The methods and tools of smart systems design and implementation were considered and evaluated. The recommendations and suggestions for the advisable ways for smart systems of open science introduction into the learning process were provided.

1. Statement of the problem

In the conditions of globalization, European integration, and accelerating digital transformation of many spheres of human activity there is a need to create a competitive educational sphere in Ukraine, formation of modern human competencies and qualifications, increase the level of accessibility and quality of education. According to SiS.net (a project within the framework of the European Union's Framework Program for Research and Innovation "Horizon 2020"), there is currently a shortage of science-oriented, "scientific-knowledgeable" people at all levels of society and the economy.

The key factor in training such people who are able to adapt to dynamic socio-economic changes, think critically, effectively solve professional and everyday problems with modern technological advances and digital solutions, engage in sustainable self-development, be successful in their profession, etc. is a cooperative effort of motivated, qualified educators.

In turn, one of the main conditions for improving the quality of educators' training, increasing the level of their professional competence, wider use of innovative pedagogical technologies, expanding the share of research approach in teaching is the introduction of the cloud-based open science systems that are smart learning systems of a new age in pedagogical and postgraduate pedagogical education. This requires substantiation of theoretical and methodological principles of creating cloud-based systems of open science in educational institutions, research of innovative models, principles and methods of their formation and use, and determination of the most appropriate ways of implementation.

It is necessary to take into account global trends in the transition to the mass introduction of research and educational platforms and infrastructures of open science, in particular, the services of the European open science cloud (EOSC), which enables the creation of a new high-power information technology ecosystem in educational institutions. Solving the problems of the introduction of cloud-based systems of open science in educational institutions is an essential prerequisite for training specialists capable of appropriate, scientifically sound application of emerging ICT in their future educational and scientific activities. It determines updating the content and approaches to modern teachers' training, the formation of their readiness for professional activity in a continuous digitalization, in particular through the introduction of smart systems of open science.

1.1. Analysis of recent research

The problems of design and use of the cloud-based services and technologies of open science in educational institutions are among the top in the field of digitalization. Cloud-based open science systems of a new generation are the smart systems as they are more adaptive, flexible, powerful, and functional, thus attracting more and more attention from researchers. Their introduction should have a positive impact on the quality of education, providing wider access to promising ICT, expanding the share of research approaches in education, and improving the quality of educational services. Problems, tendencies, and prospective ways of introducing cloud technologies of open science in the educational process were considered in many works of foreign and Ukrainian authors.

V Yu Bykov and M P Shyshkina [1] studied the issues of using the cloud-based systems of open science within the university learning and research environment in the context of integration to European Research Area (ERA).

S Lytvynova, A Manako [2] and M Pikulyak [3] considered the features of adaptive learning systems use and their management.

The issues of the cloud-based learning and research environment design at the university was studied by a group of scientists V Yu Bykov, S M Vernygora, A M Hurzhii, L M Novohatko, O M Spirin and M P Shyshkina in [4].

Y Rosen, I Rushkin, R Rubin, L Munson, A Ang, G Weber, G Lopez and D Tingley in [5] and L Balme [6] paid attention to the different aspects of implementation of adaptive learning systems for learning and P Kerr [7] considered this type of systems in the aspect of teachers' training.

The concept of adaptation and adaptability, content, and stages of adaptive technologies was studied in the work of H Yelnykova and Z Ryabova [8].

The historical development of the paradigm of open science was studied by A Grand [9]. J Lodge, L Corrin, G-J Hwang and K Thompson [10] investigated the impact of open science on research educational technologies.

Various aspects of adaptability in learning were discussed in [11]. The use of adaptive tests was described in [12].

The series of adaptive learning systems have been considered in recent years in Ukrainian research for the prospects of their use in Ukrainian educational institutions [13]. Among them, there are such as Course Arc, Realizeit, Brightspace LeaP, Mobius, WileyPLUS, Knewton, and others. We also consider the comparative analysis and evaluation of these systems by the range of indicators, made by H B Varina, V V Osadchyi, K P Osadcha, S Shevchenko and S H Lytvynova [14]. We would like to draw attention to the adaptive learning platform Knewton (`https://www.knewton.com/`), as the promising one for the implementation of teachers' training. The effectiveness of the named platform is confirmed by empirical data obtained by Arizona State University (USA) as a result of training over 2000 students. It was found that the share of students who completed the course increased (from 64% to 75%), with 45% of them completing earlier than planned. The share of non-graduates decreased from 16% to 7% [15].

Several adaptive learning aspects were discussed in the course of the Precalculus [4].

In recent years there is a tendency for the implementation of augmented reality (AR) and virtual reality (VR) technologies within the learning systems which also adds value to the adaptability o these systems [16]. VR training and assessment can have a progressive impact on productive learning [17].

Using VR / AR technologies diversify the educational process through teamwork [18].Adaptive technologies can also affect the interaction of participants in the learning process [19]. The adaptive systems that provide VR / AR technologies may be used to support the data processing [4].

Therefore, there is a need to train teachers and educational staff to implement smart systems and artificial intelligence [20].

To find out which learning platforms are used in Ukrainian institutions of pedagogical education, and whether there are adaptive ones, we conducted a survey where representatives of 31 Ukrainian institutions took part (16 pedagogical universities and 15 institutes of postgraduate pedagogical education), 2018-2019. Taking into account the adaptability indicators, we established that currently none of the surveyed Ukrainian institutions used adaptive platforms. Thus, 90% used Moodle LMS, 16% – Google Classroom, 7% – Office 365, 18% – other systems, and 7% – nothing.

We consider the following reasons why Ukrainian institutions of pedagogical education do not use adaptive systems:

- no localization, only English content and technical support;
- the potential for “bugs”, failures, as adaptive platforms are difficult to implement, so to test them flawlessly is almost impossible;
- the cost which is rather high for certain individuals, including teachers. There are currently no free adaptive platforms (trial version only).

The purpose of the research is: to consider the concept of smart systems of open science in the context of teachers’ education; to evaluate the state of the art on the problem of elaboration in Ukrainian and foreign educational spaces and to consider the possible methods, forms, and recommendations for educators on using smart systems of open science in personalized learning implementation.

2. The conceptual apparatus of research on smart systems in teacher education

Based on the analysis of research trends in education, key concepts of investigation and interpretations of the basic terms were defined.

The cloud-based learning and research platform is considered as a set of cloud-based tools for support of various training and research activities. Many different tools can be integrated within one platform, providing more opportunities for open and adaptive learning and research.

Particular attention should be paid to the formation and development of cloud-based systems, which may include a variety of services for learning and research and their combinations, which are divided into appropriate groups. Some scientists understand this concept as a system of specific cloud services. Another approach supposes that a separate cloud service acts as a cloud-based system. In this case, the cloud-based system may be considered a computer program for educational purposes, which is located in the cloud. That is, the concept of a cloud-based environment is rather broader. However, a cloud-based system is combined in such an environment with other components according to the structure of the cloud-based learning support.

The cloud technologies which provide the background for the smart systems of open science possess such innovative features being intrinsic to the cloud computing systems as openness and flexibility [5]. If the goals and objectives of the learning environment change, it is possible to adequately change its tools, as well as the overall composition and structure, to modernize the methods of their use within the cloud-based setting.

Under *the cloud-oriented methodological system* we mean a system of learning methods of using cloud services or specially designed cloud-oriented components for educational and scientific purposes, combined into a single system based on formative factors, among which there are the cloud-oriented approach and the integrity of learning content.

A smart system of open science is a cloud-based system (based on a cloud platform), which can be automatically adjusted according to the goals and objectives of the process of scientific cooperation, various individual characteristics, and the educational and scientific needs of virtual research participants.

We also make attention to the peculiarities of the content meaning and differences between the concepts of big data, smart data, and fair data as important to the design of the smart systems of open science.

Big data are the vast data sets that are accumulated in organizations daily. Then by the smart data, we may consider the data that contains information about the target audience to be segmented form. The smart data available for processing by a human mind still may be produced based on big data. Artificial intelligence techniques are used to collect and provide these data to help humans deal with them. Thus, these data may be produced automatically and also may be collected and used by humans. On the contrary, the research data are also the kind of smart data but the humans usually collect these data consciously and in a planned manner due to the reasonable research aims. Still, the adaptive research tools for data processing may be a useful instrument to support this process.

By *FAIR data* the research data that is findable, accessible, interoperable, and reusable are usually considered. These data are the most valuable if the context of open science systems design. The special tools and services are used to provide smart data processing and this is important to consider these tools among the teachers' training courses.

As a result, the introduction of open science norms in Ukraine should lead to greater exchange, accountability, reproducibility, and reliability of scientific materials and affect the learning process as a whole. In the process of studying Ukrainian and foreign experience, the following advantages of using cloud services for mathematical purposes were identified: resource savings; access mobility; elasticity, and others. The introduction of cloud platforms and services in the educational process leads to the emergence and development of innovative forms of learning and research organization focused on joint educational activities, creating more opportunities for educational and research projects. Methods and approaches of open science have a significant impact on the educational process, in particular, on teachers' education.

3. Current research developments and implementation

One of the main conditions for improving the quality of training of educational and research personnel, increasing the level of their professional competence, wider use of innovative pedagogical technologies, expanding the share of investigative approaches in teaching and learning is the introduction of smart open science systems in educational universities and postgraduate education. In this regard, there is a need for fundamental research on the design and use of cloud-based methodological systems of open science in the educational process of higher education and the professional development of teachers. For this purpose in 2021, a planned research "Methodology of using cloud-based systems of open science in educational institutions" (# 0121U107673), has been started in the Institute for Digitalisation of Education of the NAES of Ukraine devoted to the issues related to the digitalization of open science. In particular, it is planned to explore the conceptual apparatus, principles, methods, and approaches related to the use of cloud-based systems of open science in the training and professional development of teachers; identify the tools and services that are most appropriate to use in this process; substantiate and develop a model for the use of the cloud-based systems of open science in teaching and professional development of teachers; to develop the learning techniques based on the model and to check experimentally efficiency of their use.

The expected social effect of the project is to improve the quality of the educational process of higher educational and postgraduate institutions; the effectiveness of the cloud-based tools and services introduction, the rise of the level of digital competence of teachers, the wider use of open science services in the educational process. The research is devoted to the methodology of open science services implementation at different levels of teachers' education – at the institutions for teachers training and also at the pedagogical universities to train educational personnel. For this purpose, the special training courses and appropriate learning methods were elaborated and implemented at different levels.

The training course "Smart Technologies in Education" was developed for the students of the National University of Life and Environmental Sciences, specialty Information and Communication Technologies in Education, 011 Educational, Pedagogical Sciences, 01 Education / Pedagogy, 2020-2021 academic year. The module "Smart technologies of open science" was introduced within this course aimed at increasing the competencies of students in open science. The total number of students was 30. Before the start of the course, the measurements of participants' ICT competencies were accomplished, which included issues related to the use of open science technologies. Before entering the training course only 1 respondent out of the total number has comprehended the concepts of open science or open data. Instead, 23 students answered that they knew only a little about these concepts. After completing the course, the vast majority of students (75%) showed a high level of awareness of the concept of open science, and the ability to use these services, which indicated the growth of relevant ICT competencies.

The methods of using smart systems of open science in the training of future Masters of ICT in education were used to meet the educational and scientific needs of learners, and to increase the level of their ICT competence. In course of training, such methods as explanatory-illustrative, practical, partial search, problem-searching, and problem-heuristic were used. In general, the training was aimed at the practical application of services and technologies of open science, and the ability to apply them in educational and professional activities. Lectures, seminars, laboratory works, independent work, and individual and group educational projects were used as forms of learning. The learning tools included electronic resources and adaptive cloud services that can be used to support open science systems and tasks (Microsoft Office 365: Teams; Power BI; Microsoft Azure). Practical tasks were focused on creating educational projects "in the cloud", acquiring skills of presenting and processing data in a cloud-oriented environment (Microsoft Office 365), the use of adaptive data processing services (Power BI); creation and use of virtual machines to use the computing power of cloud servers (Microsoft Azure). The expected result was intended at increasing the level of organization of educational research and the ICT competence of learners.

That is, if students have low awareness of open science services, what about in-service teachers? It is possible that the problem still exists at the stage of training in educational institutions. But to draw valuable conclusions, it was necessary to survey a representative sample of teachers from all regions of Ukraine and students of pedagogical institutions of higher education. To approve the received results, to support the principles of open science, to clarify the current stage of cloud-based open science systems use the survey was conducted, a group for teachers "Open Science in Education" was created based on Google Group (e-mail: `open_science_ua@googlegroups.com`, link to the group description: `https://groups.google.com/g/open_science_ua/about`). The group is open and currently has 469 members (covering all regions of Ukraine). Every day the group grows by attracting new members.

The survey found that the majority of teachers (80%) were unfamiliar with the concept of open science, and its principles and did not know what European Open Science Cloud (EOSC) was. All respondents (100%) answered that they use only open electronic resources to search for educational literature.

To provide the necessary teachers' training the distance learning course "Open Science Cloud Services for Educators" was developed. For the whole period of study, it involved: researchers – 1, pupils and students – 2, managers of educational institutions – 3, employees of the administration of education – 7, educators of secondary schools – 10, other employees at school - 29, teachers of institutions of higher education – 58, managers of educational institutions – 66, teachers of colleges and vocational schools – 72, teachers of general secondary school – 395. Total registered – 921; joined the course – 774; completed the course – 643.

To conduct the course, the methodology of using smart services of open science in teacher training was developed. It was aimed at teachers' training and their professional development, expanding access to free cloud services, and increasing the level of ICT competence. In the course of training, the next training methods were used: the practical work; the problem-based teaching; the partial search; the problem-solving, and the explanatory-illustrative. In general, the training was aimed at learning and training the practical application of the adaptive open science tools (some cloud services, including virtual reality services) of EOSC. Lectures, computer workshops, educational and training classes workshops, webinars, explanations, individual consultations, and distance learning courses were used as forms of education. The learning tools included the services of the European Open Science Cloud and a platform to support distance learning courses (such as Moodle or Google Classroom). Practical tasks were focused on services of joint data processing and services of joint work on educational projects; using the EOSC services; mastering the skills of working with specialized cloud services, including virtual reality services, as tools of open science. The expected result was intended at expanding access to cloud services to support learning, increasing the level of organization of the educational process, in particular, the research component, increasing the level of ICT competence of learners.

To clarify the state of formation of open science competencies and evaluate the effectiveness of the proposed methodology of teachers' training, the following ICT competence components were measured: the skills and experience of communication in their disciplinary area and beyond; the skills and experience in research data management, analysis/use/reuse, dissemination. Each component was considered separately and calculated by levels: high, sufficient, medium, and low. At the end of the course, the same indicators of the open science competencies formation were measured. Analyzing the obtained results, we can conclude that the percentage of a high level of skills and experience in research, management, analysis/use/reuse, and dissemination increased to 31%, and a sufficient level increased from 9% to 24%. At the same time, there is an increase in the number of course participants who have a sufficient level of skills and experience in their disciplinary community and beyond: from 38% to 41%.

4. Recommendations, suggestions

The introduction of smart systems of open science in educational institutions is an essential prerequisite for training specialists capable of appropriate, scientifically sound application of promising information and communication technologies in their future educational and scientific activities. The above necessitates updating the content and approaches to teachers' training, the formation of their readiness for qualitative professional activity in education digitalization, in particular through the introduction of smart systems of open science.

Thus, the structure and composition of the training courses may be reconciled with the planned development goals and new challenges that may arise in the future. To do this, it is necessary to consider and implement the methodological cloud-based system, which includes some separate methods of using cloud-based components for educational purposes in the teachers' training.

Among the areas of smart systems of open science introduction for teachers' training, there are such as:

- To support individual and collaborative forms of learning activities in the classroom and also in the extra classroom using the services of the public cloud-based platforms for educational purposes, for example, Microsoft Office 365 (Microsoft Teams), G Suite for Education, FaceTime, Google Duo, Hangouts and other;
- To include the cloud services of open science, in particular, the services of European open science cloud into the process of teachers' training and professional development in educational universities and postgraduate training;
- To create the smart systems of open science in educational universities including facilities and services of scientific-educational information networks; cloud databases and data collections, cloud-based office software applications, specialized software training tools, as well as EOSC services;
- To introduce and implement specially designed and tested cloud-based methodological systems into the process of educational personnel training at different levels.

5. Conclusions

In the conditions of globalization, European integration, and accelerating digital transformation of many spheres of human activity there is a need to create a competitive educational sphere in Ukraine, formation of modern human competencies and qualifications, increase the level of accessibility and quality of education. One of the main conditions for improving the quality of training of pedagogical, scientific-pedagogical, scientific personnel, increasing the level of their professional competence, wider use of innovative pedagogical technologies, expanding the share of research approach in teaching is the introduction of smart open science systems in pedagogical and postgraduate pedagogical education.

As a consequence, the introduction of open science norms in Ukraine should lead to greater exchange, accountability, reproducibility, and reliability of scientific materials and affect the learning process as a whole. In the process of studying Ukrainian and foreign experience, the following advantages of using cloud services for mathematical purposes were identified: resource savings; access mobility; elasticity, and others.

The introduction of cloud platforms and services in the educational process leads to the emergence and development of forms of organization of education and research focused on joint educational activities, creating more opportunities for educational and research projects. Methods and approaches of open science have a significant impact on the educational process, in particular, teacher education. Prospects for further research are the study of tools and services for the formation of cloud-based open science systems in educational institutions, justification, and development of methodological system use of cloud-based open science systems in the educational process of higher pedagogical, postgraduate pedagogical education institutions, providing guidelines for teacher training.

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The phenomenon of “clip thinking” in the educational and cognitive activities of students of natural and physical-mathematical educational profile

The phenomenon of "clip thinking" in the educational and cognitive activities of students of natural and physical-mathematical educational profile

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Abstract. The article presents an analysis of the phenomenon of "clip thinking" in the educational and cognitive activities of students of natural and physical-mathematical educational profile. The involvement of clip thinking in the initial stage of cognition in comparison with rational and theoretical thinking is theoretically substantiated. An empirical verification of the originality of cognitive processes of students of natural and physical-mathematical educational profile in the situation of comparing traditional linear (textual) and hypertextual way of presenting information is established. Deficiency of cognitive processes characteristic of clip thinking for results is revealed, which is characterized by characteristics of mental (theoretical) level of cognition. Therefore, the next stage of cognition should be the understanding of information through the mechanisms of comparison, generalization, categorization and re-synthesis.

1. Introduction

In the process of translating the information space into "digital" there was a rapid increase in text, visual and audio materials, which in turn became publicly available. The person who plunges into this space is faced with the dilemma of choice, which is the intention to cover as much information as possible and thus narrow this choice to the optimal for this cognitive task with minimal time. As a result of this contradiction, in the cognitive processes of perception and awareness there is an attitude to isolate relatively short information segments. In particular the traditional linear text is replaced by bright headlines and short articles, whose main task — to create not logical representation but emotional attitude to events. The change of linear text by hypertext has led to the existence of many channels for obtaining information in the absence of its systematic presentation. T. Nelson [1, pp.59–60] coined the term "hypermedia", in which he described the nonlinear environment of perception of various kinds of information. Unlike hypertext, hypermedia is a collection of text, video, graphics, audio, and other types of information that are combined by hyperlinks. These changes determined the emergence of the phenomenon of so-called "clip thinking". F. I. Girenok [2, pp.174–175] believes that conceptual thinking is inferior to the phenomenon of "clip thinking". In the culturological concept of K. G. Frumkin [3, pp.32–33] substantiated the preconditions for the phenomenon of this type of thinking: the growth of information flow, which led to a tendency to reduce it, the separation of the main and filtering the superfluous, increasing the speed of updating information and its diversity, increasing dialogue at different levels of social system. The transformation of the information space motivates a person to restructure perception and thinking, which is dominated by fragments and switching from one information segment to another. Not concepts and inferences dominate in thinking, but images, emotional representations, visual images.

The transition to an appropriate style of perception and understanding of information, which is presented in the phenomenon of "clip thinking", is becoming more and more characteristic of modern students and significantly affects the process of acquiring professional knowledge. The rapid development of information technology has led to almost complete digitalization of education. Thus, the main assistants of students in their studies were media resources and electronic sources of information. Searching for the necessary information on the Internet for private purposes for student youth by analogy becomes a style of information retrieval and selection of information for educational purposes. We assume that the essence and mechanisms inherent in clip thinking become a kind of cognitive style and rapidly penetrate into the process of cognition of students.

The purpose our work is a theoretical analysis of the mutual correspondence of levels of knowledge and types of thinking, as well as the essence of cognitive processes inherent in clip thinking and empirical verification of the cognitive processes of students of physical and mathematical and natural education profiles.

2. Literature review

The foundation of natural science knowledge is the ability to test the results on the basis of which the scientific hypothesis. Therefore, the basic principles of training students of physics, mathematics and natural sciences include the requirements to master the fundamental laws of the physical world and the world of living organisms, to have scientific methods of cognition.

Students gradually acquire basic knowledge in the field of mathematics, physics, computer science, biology and chemistry, studying the main sections of the relevant scientific disciplines. The linear way of fundamental training in the field of physical and mathematical and natural education is the opposite of the tendency of modern students to clip thinking. Despite the significant disadvantages of this cognitive style, among which is the unwillingness to painstaking analytical work and building a chain of logical reasoning, we cannot fail to note the advantages of this style: setting for simultaneous setting of many tasks, fast orientation in the information flow.

The strategy of searching for information, rather than its independent acquisition by scientific methods, is beginning to dominate modern specialists in various fields, including natural sciences. The main thing for them is the ability to navigate in different information sources, choose the right information for use in practice. A significant number of graduates need to be quick to acquire the necessary knowledge and relevant skills. This requires flexibility and speed of thinking, skills in working with various software products and media resources. Fundamental science training does not always provide such competencies. On the other hand, humanities knowledge in the field of philosophy, history, psychology, pedagogy, sociology increases human adaptability in the current world, because such knowledge is less formalized than natural or mathematical.

Consider the features of the cognition process as such. In the process of social evolution of mankind, a special type of knowledge was formed, which is realized in conscious purposeful activity, the ultimate goal of which is to obtain new knowledge. The presence of this specialized activity has become an attribute of culture and civilization.

Cognition, according to A. B. Nevelev and N. L. Hudyakov [4, p.48], is the process of activity, socio-practical assimilation of human forms of the material world, in the case of which, forms with their depth in the structure of things "move" into human consciousness, and become instrumental and symbolic knowledge. According to O. B. Kulikova [5, p.15], cognition is a process of purposeful search by a person of everything that will provide him with the opportunity to create himself and find his place in the world. Scientific knowledge, according to V. S. Grekhnev [6, p.14], it is always a process that consists of two important points: 1) collecting information about the object; 2) analysis of the received information. Thus, cognition will be understood as the process of purposeful human acquisition of knowledge about the surrounding reality.

It is traditionally believed that cognition occurs on two levels [7, pp.56–57]. Sensory (empirical) cognition is carried out through the sensory-perceptual system of man, which has complex and compensatory properties. Also, the peculiarities of the first level is that cognition does not go beyond individual statements about certain phenomena and the consideration of direct links between them. That is, at this level, objects are observed, facts are recorded, experiments are conducted, empirical relationships and patterns are established. The main forms of the sensory level are sensation, perception and imagination. For the most part, the acquired empirical knowledge is subjective.

The rational (theoretical) level is characterized by a more complex way of reflecting reality, through which a person can go beyond their sensory experience and learn what is not directly given at the initial stage. This method involves a set of mental operations, which corresponds to the movement of thinking from knowledge of phenomena to knowledge of the essence. The main features of this level are that it is based on the results of sensory cognition, but does not interact with the object of study. Therefore, it is possible to study phenomena that in the case of the use of sensory cognition is impossible to know, and the result is essential knowledge about the object. The main forms of such knowledge are concepts, judgments and inferences. That is, it is at this level is the further development of empirically acquired knowledge.

Quite common is proposed by I. Kant [8, pp.356–359], a variant of the distribution of levels of knowledge depending on the types of thinking: reason and mind. Reason is everyday life thinking, which is the initial stage of cognition, in which the operation of abstractions takes place within a rigid standard. Its main function is to distinguish facts based on the form of knowledge, rather than its content. The mind (theoretical thinking) is a higher level of rational cognition, which is characterized primarily by creative operation of abstractions and conscious study of their content. The main task of the mind is to combine various facts and identify the driving forces of the studied phenomena.

This opinion is also held by V. A. Vazyulin [9, pp.175–179], who believes that rational thinking dominates the path of cognition from the chaotic idea of the whole, from the sensory concrete to the abstract, from living contemplation to abstract thinking. Mental thinking on the path of cognition from abstract to concrete, ie from abstract thinking to practice. Also, the scientist emphasizes the interdependence of the proposed types of thinking. Therefore, the general course of cognition occurs simultaneously in opposite directions, with a qualitative change of the dominant direction to another, with the transition from one stage to another.

Despite the relationship of these types of thinking, in our opinion, mental concepts are significantly different from rational concepts. If the latter can only be connected and disconnected, then mental concepts develop, move, pass into each other. That is, the first type of thinking is the basis for the second, when there is a formalization and transition of the obtained facts into a relatively stable state due to the mechanisms of generalization and categorization. In epistemological concepts there is still no thorough analysis of the phenomenon of “clip thinking”. The advantage of clip thinking is the high speed of information processing. As I. O. Danchenko and V. O. Tyurina point [10, p.635], such thinking seems to bypass the analysis, creating new ways and speeds up the process of perception. The subject of cognition with a tendency to the cognitive style of “clip thinking”, according to S. M. Soboleva [**?**, pp.88–89], operates with meaningful units of fixed length, and outwardly this is manifested in the fact that a person can not focus for a long time on any information, it reduces the ability to analytical and synthetic activities.

Based on the above, we offer a theoretical comparison of the essence of the phenomenon of "clip thinking" and types of thinking that are dominant at each level of knowledge (see table 1).

Table 1. Theoretical comparison of the phenomenon of clip thinking with the types of thinking inherent in each level of knowledge.

Criteria	**Kind of thinking**		
	clip	prudent	mental (theoretical)
		level of knowledge	
		empirical	theoretical
Goal	processing a significant amount of information, identifying individual facts	recording facts, conducting empirical research.	detection, the formation of relationships between the identified facts.
interaction with the object of knowledge	directly		in the imagination (based on existing images)
features of cognition	-clarity and objectivity; -reproduction of external sides and properties of the object		-abstractness and generalization; -reproduction of internal regular connections of the object.
speed of information perception	high	sufficient	low
features of information analysis	inability to qualitatively analyze information		the ability to track and separate cause and effect relationships.
concentration	reduced	sufficient	high
switching attention	fast	enough	low
the result of cognition	smattering	establishing an empirical relationship between individual phenomena	in-depth, high-quality knowledge.

As we can see from table 1, clip thinking is similar to rational, which dominates the empirical level of knowledge, in such criteria as interaction with the object of knowledge, especially the analysis of information. That is, these two types of thinking interact directly with the object of knowledge, and the result of this style of thinking is either superficial (life) knowledge, or the establishment of an empirical relationship between individual phenomena. According to other criteria, no similarities were found between them. It is noticeable that according to the essential characteristics, the opposite of clip thinking is theoretical thinking, which is capable of comprehending meanings, creating a holistic picture of the world. However, this type of thinking and the corresponding cognitive style is becoming a sign of the scientific community, people professionally mature. We assume that modern students have another trend - the transition to a cognitive style, inherent in the phenomenon of "clip thinking". Thus, summarizing the results of comparative analysis, we can assume that in the general phenomenology of cognition, the mechanisms of clip thinking provide the first stage of cognition, which presents individual empirical facts, which contain the author's opinion, which may not be an expert in the field it represents the material. That is, the obtained data is only a material in which the subject is presented with the subject content, and which in the process of perception and comprehension undergoes various ways of cognitive transformation.

Cognition, in this case, is not a copy of reality, but the process of making cognitive hypotheses, ie the prediction of new objects, properties, processes, and then their understanding through critical analysis and subsequent synthesis. In addition, it is appropriate for the initial stage of cognition, in our opinion, is to take into account such a property of perception as integrity. This concept is usually understood as an integrative image, which is formed as a result of the synthesis of the original elements. At the same time, this way of constructing and integrating images is given by an extremely broad whole "image of the world", through which the experience of cognition and life of the subject, which goes far beyond the existing situation, participates in every act of perception [12, pp.252–253]. That is, the formed holistic image, which includes sensory images of different levels of community, goes beyond the subjective present and carries, along with specific local knowledge and individual context, the most general information about reality.

Thus, summarizing the above, it can be argued that clip thinking should be considered in the context of the initial stage of cognition, which allows the transition to other levels of this process. However, it should be noted that the levels of knowledge are interdependent and in the actual functioning of knowledge there is a constant interaction between them.

3. Method

To confirm our assumption about the transition to cognitive style, inherent in the phenomenon of "clip thinking" in modern students, we conducted an experiment with such category of different specialties of the university. The aim of our study was to identify the peculiarities of information perception and further cognitive processing of information presented in the format of linear text and video (visual).

The total sample was 68 people, students of physics, mathematics and natural sciences, age 20–24 years. Of these — 10 men and 58 women. We proceeded from the assumption of originality in the perception of educational information of a humanitarian nature in different versions of its presentation (General Psychology course for students of the faculties of FM and Natural Sciences).

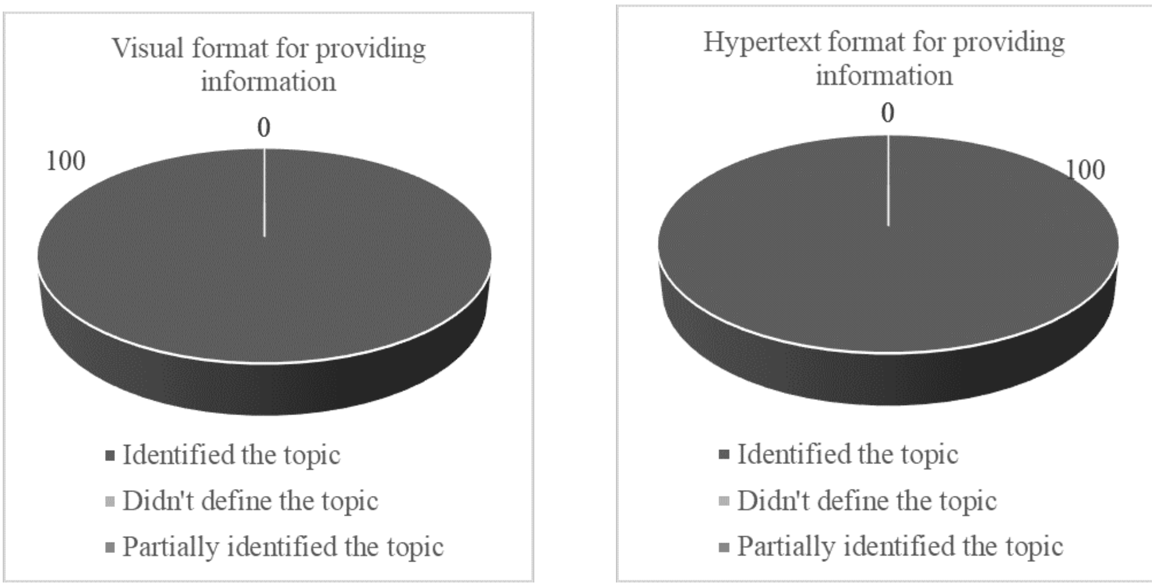
The experiment was conducted as follows: the subjects were provided with information about borderline personality disorder in two versions of the text: linear text and hypertext format, which combines visual representation of information in parallel with audio information, which is common name hypertext.

By definition, G. M. Gich [13, p.40], these are texts whose texture consists of two inhomogeneous parts: verbal and nonverbal. That is, information is provided by text and supported by images, animations, tables, etc. A slightly different definition is given by E. D. YAstrebova and A. V. Merzlyakova [14, p.181], namely hypertext is a minimal block or piece of information that contains a complete thought, a logically complete idea. The opinion of G. O. Zvezdina is interesting [15, p.3], which indicates that hypertext is a form of organization of such material, the units of which were not a linear sequence, but a system of transitions to other possible elements and new connections. Following these connections, you can read the material in any order, forming different linear texts. Thus, analyzing these and other scientific sources [16, 17], we can assume that hypertexts are the result of the rapid development of information technology, and contributed to the emergence of clip thinking. Therefore, the second format for providing information in our experiment was a short video (8 minutes) typical of social networks.

The experiment was performed in two stages with an interval of 2 weeks. The group was divided proportionally into two subgroups. In the first stage, one subgroup studied the test and the other perceived the video content. Two weeks later, the tasks for the subgroups changed. To check the quality of perception and residual memorization, a Google form was compiled from the question to the content of the text, which needed to be answered openly.

4. Results

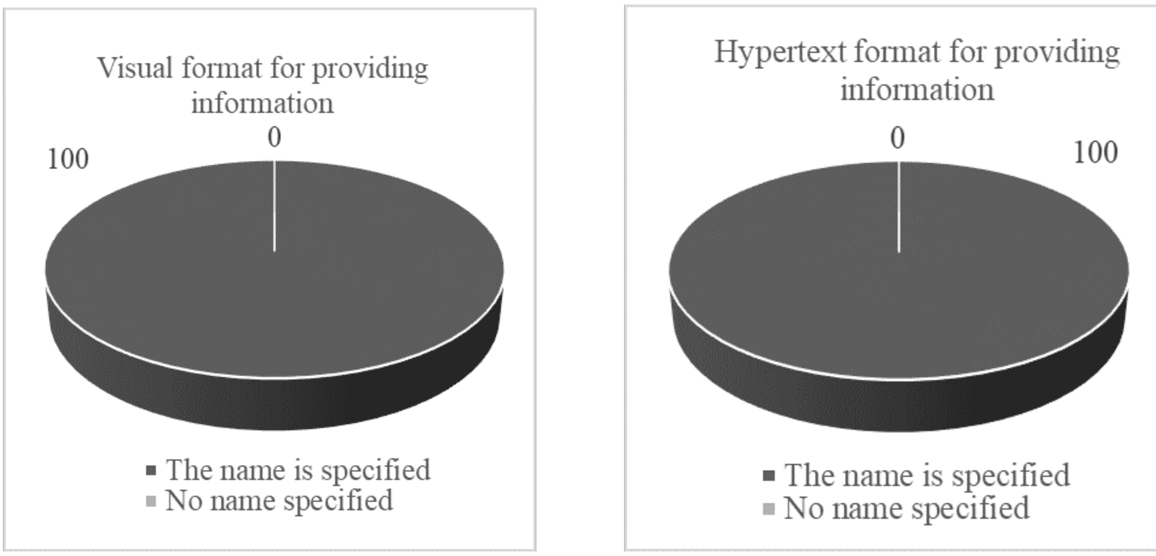
The results were obtained, which will be presented in the following figures. The first question was to name the topic of the presented text (for both the first and the second format of providing information), the results are presented in figure 1.



(a) (b)

Figure 1. Answers to 1 question in visual (a) and hypertext (b) formats.

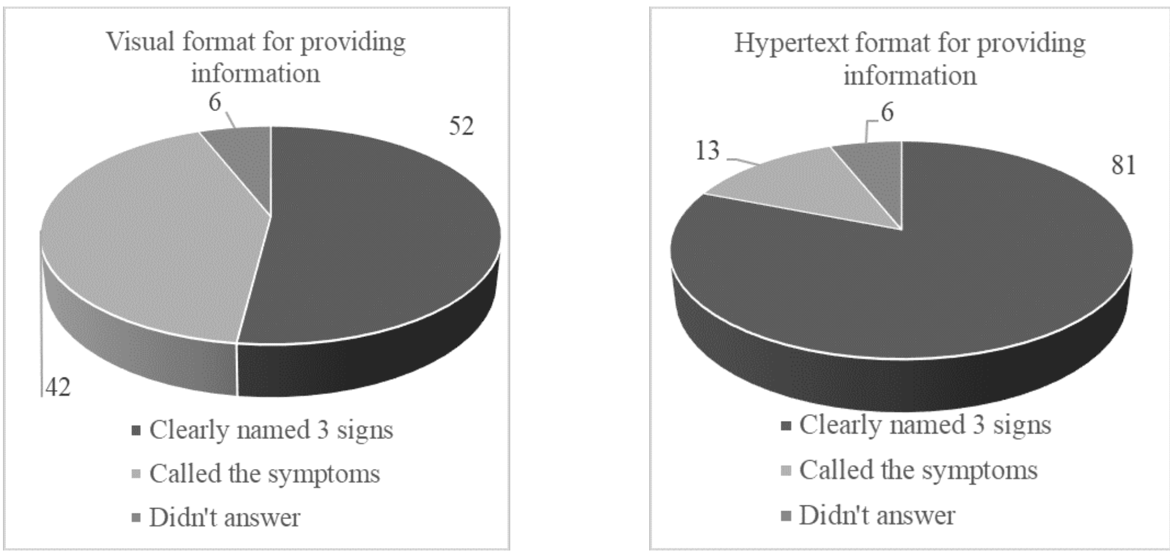
As we can see, the students coped with the task 100%. That is, they are able to highlight the purpose of the text, in any format in which it will be provided. The second question was to name the additional name of borderline personality disorder, which was given at the beginning of the text. The results obtained in figure 2.



(*a*) (*b*)

Figure 2. Answers to 2 question in visual (a) and hypertext (b) formats.

Figure 2 shows us that the students did a great job with this task. Let's move on to consider the answers to 3 questions, which sounded like this: "Name the main features of borderline personality disorder". In the text, the main features of the disorder were three characteristics: instability of the image of "I"; instability of emotions and relationships. In addition, there were 10 symptoms (anger, dichotomous thinking, impulsiveness, excessive efforts to avoid the fate of being abandoned, unstable relationships, etc.), which may or may not occur. The results are presented in figure 3.

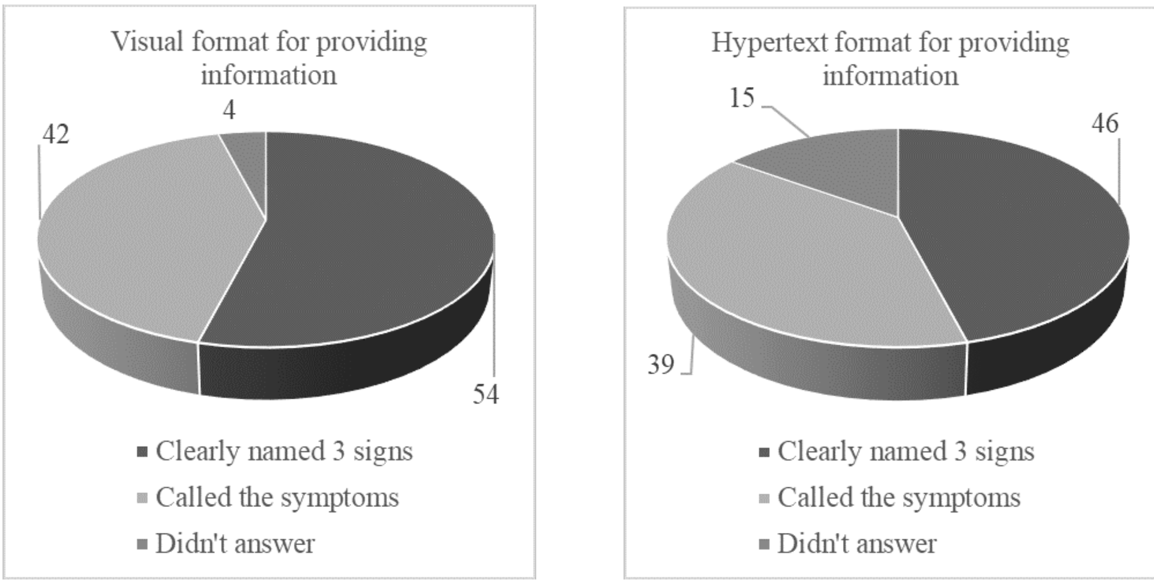


(*a*) (*b*)

Figure 3. Answers to 3 question in visual (a) and hypertext (b) formats.

In this case, as we see from figure 3, the results differ significantly. That is, when the information was provided in video format, a smaller number of respondents (42%) gave the correct answer, in contrast to the text, where 81% of respondents gave the correct answer. Also, it should be noted that in the first version, students had a confusion of the concepts of "sign" and "symptoms", which did not happen when working with traditional linear text. This may indicate that students' quality of perception and understanding is higher when working with information that is presented in the text and symbolic form. Visual-audio form of information presentation has the worst effect on the quality of perception. The number of students who failed the task was the same in two cases (in each case they were different students).

Consider (see figure 4) the answers to 4 questions, which required three criteria by which to state the presence of borderline personality disorder (social maladaptation, totality, stability of manifestation).



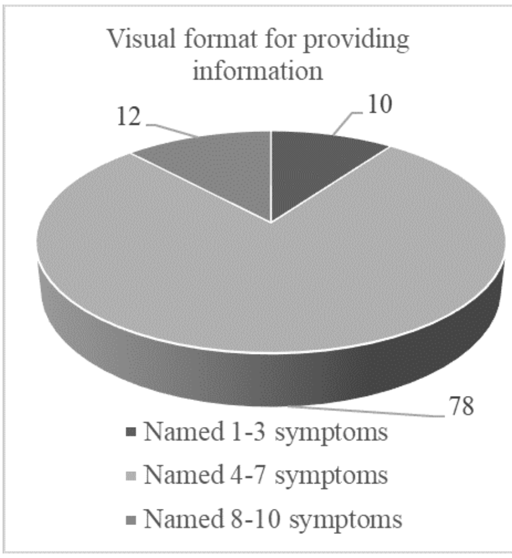
(*a*) (*b*)

Figure 4. Answers to 4 question in visual (a) and hypertext (b) formats.

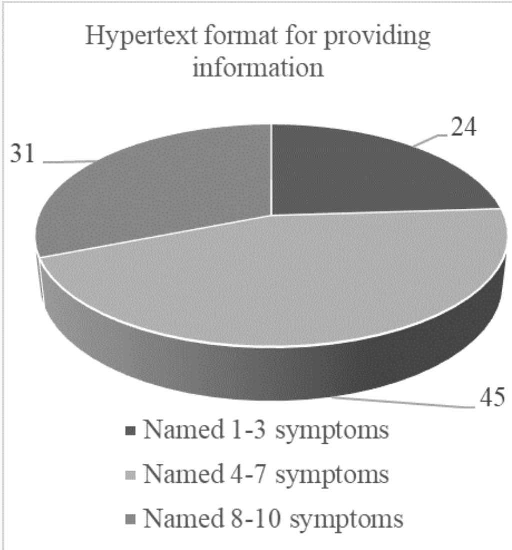
An interesting trend is observed on this issue. As we see from figure 4. formed the essence of 3 criteria in the visual format of information – 54%, and in the perception of linear text – 46%. The criteria were confused with symptoms in the first case – 42% of respondents, almost the same number in the second format – 39% of respondents. 4% did not provide an answer in the visual format, 15% in the linear format.

This result does not continue the trend highlighted on the third question. It is can be explained by the fact that in the text that is printed, the information must be divided into semantic parts. In the audiovisual format, the text is presented in separate frames, remembered with the best result.That is, students do not need to perform intellectual actions in this format. The information is provided in the format they are familiar with on a daily basis on social networks. Separately provided facts are quickly perceived and remembered, but it should be remembered that they will not be combined with what is already known, as evidenced by the results of the study.This can be explained by the low level of development of concentration and endurance of attention, low motivation to learn. Therefore, in order to get a clear answer as to why this is happening, additional research is needed.

The fifth question was: "List the main symptoms of borderline personality disorder". Consider the results obtained in figure 5.



(*a*)



(*b*)

Figure 5. Answers to 5 question in visual (a) and hypertext (b) formats.

We can see from figure 5, in the case where students were provided with information in audiovisual format, the majority (78%) indicated 4–7 symptoms, while in text format only 45%. Only 1–3 symptoms were indicated in the first case 10%, in the second — 24%. But they named more than 8 in the first case — 12%, in the second — 31%.

This indicates that, there were fluctuations in the volume and accuracy of reproduction with a single perception of information. In the part of students who listed more than 8 symptoms (the main clinical picture of the disorder), those who perceive the printed text better prevailed. The same trend is observed for "inattentive" students who were able to remember 1-3 symptoms. In the group of 3–7 symptoms, on the other hand, there were longer students who reproduced the clinical picture based on the audiovisual context.

Thus, such a basic level of knowledge is quite possible in the case of hypertext messages and audiovisual content. Summarizing the results obtained, we can say that there is no significant difference in students' perception of texts, both visual and textual format. However, each such way of presenting information has its own peculiarities: in the audiovisual format, information that is small in volume is better perceived, while in linear text, this information is perceived worse. Instead, the most complete answers were given by students who prefer a linear text.

5. Conclusions

As a result of the comparative analysis, a theoretical hypothesis emerged that the mechanisms of clip thinking work at the initial empirical level of cognition. According to such criteria as interaction with the object of cognition, features of information analysis, the essence and mechanisms of clip thinking are similar to rational thinking at the empirical level of cognition. In the course of such a process of thinking the subject of cognition directly interacts with the object of cognition, the result of this style of thinking is either superficial knowledge or the establishment of an empirical relationship between individual phenomena.

Then an experiment was conducted, which compared the effectiveness and quality of understanding information and its reproduction in terms of two ways of presenting it – text and audiovisual (hypertext). The above results indicate the different cognitive styles of students and their preferences in the perception of information in educational activities. Preliminary analysis and selection of necessary information takes place in students through the mechanisms of clip thinking. In order for this process to end with the result of the characteristics of the mental (theoretical) level of cognition, other cognitive processes are needed, namely its comprehension of information through the mechanisms of comparison, generalization, categorization, re-synthesis. These processes are better represented in the perception and understanding of traditional linear text.

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A blended English for Specific Purposes course with the focus on critical thinking skills development for computer science students

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A blended English for Specific Purposes course with the focus on critical thinking skills development for computer science students

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Abstract. The paper deals with the pedagogical aspects of blended learning implementation in the educational process of undergraduates majoring in computer science. Certain peculiarities of blended learning for foreign language teaching have been presented. The design principles of a blended course for one term as well as the practice of its functioning have been discussed. The blended English for Specific Purposes course for computer science students with the focus on critical thinking skills formation and development has been introduced. One specific profession-related theme studying within the blend has been described. The experience of applying authentic demonstration videos in the English language as contents of tasks for critical thinking skills enhancing has been propounded. Practical aspects of carrying out a 30 multiple-choice question test for determining the undergraduates' critical thinking skills level have been presented.

1. Introduction

Efficient forms, methods and approaches of the professional training of specialists in different fields have been the search aims of researchers and practitioners for decades. Nowadays, the Covid-19 pandemic outbreak has drastically changed the attitude towards the education: training goals, means, tools and relationships of teachers and students have been reconsidered, the attention focus has shifted from the final result to the emerging challenges of the educational process due to the switch from conventional schooling to online learning or blended learning.

Isolation regulations have globally influenced the way of teaching and have become the most effective incentive to try out and to implement all the possible tools in order to ensure learners' motivation and therefore their advance. In order to remain demanded by learners large-scale courses, syllabi and separate topics had to be adjusted to the blended learning mode. Instructors and lecturers had to accommodate themselves to new circumstances and to lack of personal interaction within education.

English for Specific Purposes is a course that suggests developing the communicative competence for future IT specialists. The methods for forming the 21st Century skills, which application has appeared to be difficult in the new lockdown conditions, have been reconsidered by English instructors. Advantages of blended learning have been contemplated again, taking into account online learning environment assets as well as the share of the learning online time in the educational process have effectively expanded and techniques of face-to-face interaction have been adequately modified.

The most successful transformation is naturally inherent in computer science student training since they have always demonstrated notable achievement in adopting any technological novelty. In this way, English instructors had to combine present recommendations for successful professional training, current professional IT environment requirements for critical thinking skills, and emerging ways to adjust blended learning for English for Specific Purposes.

2. Blended learning in foreign language teaching

The crucial importance of learning foreign languages for students majoring in Computer Science has been recognized by all the participants of the educational process, by education administrators, potential employers, stakeholders etc. Its significance for Ukrainian students has been formalized in a number of normative national guidelines and regulations. The recommendation letter of the Ministry of Education and Science of Ukraine "On the organization of studying humanities" No 1 / 9-120 dated March 11, 2015 states that "it is necessary to create conditions for the study of English as a language of international academic communication, in order to reach B2 level in accordance with The Common European Framework of Reference for Languages" [1]. The letter of the Ministry of Education of Ukraine "On improving the quality of training for the IT industry" [2] indicates the need to review the content of obligatory disciplines, foreign language disciplines, economic and jurisprudence disciplines taught in the training of IT professionals in accordance with modern information technology.

The necessity of the sufficient level of the foreign language knowledge has been emphasized during the development of the range of the higher education standards of Ukraine for the field of knowledge 12 "Information technology" where certain requirements for foreign language competence have been represented. According to the standards alumni with the bachelor's degree are to have the ability to use a foreign language in written and oral communication [3]. Alumni with the master's degree have to be able to use foreign languages in their professional activities [4].

As students majoring in Computer Science have been proven to be open to advances, blended learning implementation has not seemed to be a huge issue recently. Moreover, blended learning foreign language courses existed significantly prior to the pandemics.

P. Neumeier [5] describes blended learning as "a combination of face-to-face (F2F) and computer-assisted learning (CAL) in a single teaching and learning environment". The researcher points out that finding the most efficient combination of these two modes is the most important aim of blended learning. The author insists that "both of these modes can facilitate a huge variety of different communication models, tools and forms that allow for the implementation of different language learning methodologies and the formation of different social settings". She emphasizes that to design a blended learning environment the teacher is not only to choose the innovative content, but to provide for participants' individualities, their flairs and behaviour. Ideas of K. Krause [6] are close to the definition above. He states that "blended learning is realized in teaching and learning environments where there is an effective integration of different modes of delivery, models of teaching and styles of learning as a result of adopting a strategic and systematic approach to the use of technology combined with the best features of face to face interaction". Supporting these ideas D. Lim and M.Morris [7] state that blended learning can have various combinations of numerous elements: offline and online learning, live and collaborative learning, structured and unstructured learning, work and learning, and mixing synchronous and asynchronous formats. The researcher emphasize that in blended learning two media of instruction are used: the traditional methods and a technological mode of instructions.

P. Sharma [8] defines blended learning as a system that joins face-to-face classroom teaching with an appropriate use of technology, where technology can be applied to a wide variety of components. Considering the concept of blended learning, the author indicates three obligatory requirements for its functioning: various teaching methods, physical presence of both teacher and students, elements of control such as time and pace, and at least some instruction mediated through technological platforms for content delivery.

D. Bath and J. Bourke [9] describe three modes for blended learning. Mode 1 presupposes that technology is used for uploading information and resources and for carrying out main administrative functions. When technology is used for enhancing the quality of the student learning experience through interactive learning activities, this level is considered to be Mode 2. In Mode 3, technology applied for supporting learning that is mainly self-directed also involves the use of interactive and collaborative learning activities. Taking into account the character of these activities, Mode 3 is the mode with the highest level of technology integration. When using blended learning in its third mode, there is a kind of immersion in a technological environment with coordinated interaction between online learning and face-to-face learning.

Numerous studies on blended learning have been carried out by researchers in foreign language teaching. J. Rivera in his research of effectiveness and application of blended learning in teaching and learning foreign languages [10] proves that most teachers agree that blended learning in this aspect is helpful and is to be implemented, but “teachers need appropriate training on the designing of blended learning courses and activities to teach foreign languages to the students”. L.Wang [11] has conducted a theoretical research of a four-step model in the College English blended teaching process which is based on outcome-based education approach, the main characteristics of which are clear objectives, process flexibility, comparability and participation, and includes according to C. Acharya [12] defining, realizing, assessing, and using. The researcher emphasizes that the four-stage model “forms a closed-loop system oriented by learning outcome”. The foreign language course theoretically is “a kind of hybrid teaching mode, which combines online and offline teaching and practice contents”.

3. Blended learning in teaching English for Specific Purposes to computer science students

Blended learning is one of the most productive ways to combine teacher’s guidance and independent learning modes under the conditions of online education expansion. Nowadays, when most undergraduates make early efforts to get employment in their professional sphere and due to COVID-19 limitations effective time allocation for work and study is one of the most important advantages a university can offer to its undergraduates and post-graduates. At Dmytro Motornyi Tavria State Agrotechnological University, students are given the opportunity to apply for a dual learning programme or for an individual study plan if they get a job by their future trade. In order to provide both the attendees of conventional classes and employed undergraduates with all the necessary knowledge, skills and competencies within the discipline course blended mode syllabi have been developed [13]. Basing on the experience of development and implementation of the American English course for computer science students [14], which has proven to be both highly efficient and demanded by the undegraduates, we have developed a blended course focusing on critical thinking skills development.

The presented blended English course is laid out based on the common principles of all the distant learning courses at Dmytro Motornyi Tavria State Agrotechnological University in order to facilitate the transition to the blended learning. The second-year students are going to continue learning English in the blended mode for four more terms, so the entire suite of the English for Specific Purposes and the Profound English courses is designed on the same principles and with the identical structure (laying out text and digital tutorial material, developing training and assessment tests). Thus, not only English teachers and facilitators from the department of the foreign languages, but also IT specialists are involved into the designing process. One of the mentioned above courses is the ESP course for the second-year students majoring in computer science.

The obstacle to the successful blended English course implementation into the university study are low motivation of the attendees who do not strive for employment in an internationally functioning IT enterprise and allegedly do not need to improve their present level of command of English. Another problem that needs to be taken into consideration in advance is technical issues – both teaching staff and course attendees need to have electronic devices with the Internet access and to be instructed how to use an online conference application and a learning platform or an online course management system.

Within the blended English for Specific Purposes course, there are three main goals to be achieved: improvement of the level of command of English, inculcation in computer science undergraduates professional skills for successful collaboration and immersion into working environment and developing the 21st Century Skills.

In order to allocate time and the study load effectively, learning strategies, linguistic aspects (like complex grammar and vocabulary ones) and authentic text processing techniques are included into the traditional learning mode. Time consuming tasks like studying authentic texts, audio and video materials in English as well as collaboration, initiative, problem solving, critical thinking etc. tasks are placed within the self-study mode of the ESP course. Within the study load of the course in the spring term of the second academic year, 52 academic hours are allotted for classroom learning (in comparison to 38 academic hours for independent learning), so traditional learning prevails. The modes are arranged in the timetable in the following way: in a week, 4 hours are allotted for traditional study and 2,4 hours are provided for independent student learning. With the exception of two tutorial weeks and two module test weeks, undergraduates have 6 weeks in the first module and 7 weeks in the second one. The traditional learning takes place either in classrooms and as the need arises in computer classrooms of the university or (under the lockdown conditions) online – video conferences are held according to the study schedule. The class duration at Dmytro Motornyi Tavria State Agrotechnological University is the following series: 45 minutes of study – a 5-minute-break – another 45-minute-lesson. The independent learning part of the blend could be mastered by the undergraduates wherever and whenever they feel it appropriate and convenient. For the independent learning mode, the same succession of study and rest is recommended to students for the best material comprehension. Nevertheless, in the blend, the students are given an entirely free choice of how much time to spend on the topic study and of how many additional resources provided on the Moodle platform to use. The modes have the linear content structure and the consecutive complexification of the 21st Century Skills task within the spring term is foreseen.

The methodology of the blend employs the learner-centered approach, the task-based approach and the communicative method. The interactional patterns include individual, pair, mini-group and team work, face-to-face communication between teachers and students as well as peer reviewing. Teachers are expected to be rather facilitators than instructors since professional skills will help undergraduates significantly acquire new vocabulary and to process the major part of text tasks. Moreover, the learners' autonomy share depends on their striving for high study results: for A-grade students its share averages 80 to 90 per cent, for E-grade undergraduates the foreseen minimum is 40 per cent of independent study. The process of independent study technique inculcation in students starts with the thorough guidance, the teachers' introduction of the easy-to-follow study path precedes the guided self-study sessions, the detailed study plan is represented in the ESP syllabus. Introductory lectures are succeeded by trainings and workshops. The weekly tutorial hours are offered for face-to-face communication with the English teachers for the students having difficulties in embracing the independent study mode.

The traditionally recommended ratio of learners to teachers in the blend is six course participants (maximum ten) to one teacher. Nevertheless, there is no possibility to lessen the number of students in a group because of the possible study load increase. Thus, 15 to 25 students are assigned to one teacher, who sometimes is also a course designer, facilitator and teaching assistant and performs all the tasks from syllabus drafting to assessing handed in students' works by themselves. The student assessment consists of sitting four unit and two module tests and a final pass or exam. The assessment system includes not only scoring by a teacher, but also teacher-student cooperative progressing evaluation, peer reviewing and peer scoring.

The blended English for Specific Purposes course has been scrutinized in order to estimate its effectiveness in comparison with traditional ESP courses. The evaluation system included informal conversations, regular student questionnaires and a post-course survey, the ESP teachers' reflection on the course employment challenges and advantages.

Based on the evaluation results, the introduced blended ESP course has been redesigned according to the new study load and upgraded with new authentic study materials according to the student feedback. As all the ESP syllabi are transitional because of the yearly study load changes, the complexification of the linguistic materials and the 21st Century Skills tasks is planned based on the results of the learners' entrance level test in the study year 2022-2023. The second year students who have been introduced the blended ESP course from the moment of the study at the department in the autumn term in 2021 are going to be more advanced in their independent learning and processing authentic materials and developing the 21st Century Skills than students who had a traditional ESP course in their second year in 2020-2021. The results of the presented blend implementation are also important for designing blended ESP courses with the prevailing online study share. Lots of specialities at Dmytro Motornyi Tavria State Agrotechnological University have the study load that comprises four credits with independent learning share providing twice as many classroom learning hours. Blended learning is an effective solution for utilizing every academic hour for undergraduates in the dual learning programme or having an individual study plan as well as for both students and teachers under the COVID-19 restrictions.

The mentioned above ESP course for the students majoring in Computer Science comprises 12 topics at the end of the second term of taking English. The major part of the learning material is retrieved from the Infotech. English for Computer Users Student's book (published by Cambridge University Press) [15]. The rest of the professionally oriented information (in text, visual and multimedia formats) are abstracted from the open sources on the Internet and prepared for student's processing both content and linguistic aspects.

The theme which is going to be analysed creates the intense undergraduates' interest. It is the unit devoted to new technologies comprising pages 150-154 and meant for 6+6 academic hours (shared equally within the blend). It is the last theme of the spring term consolidating all the previous linguistic material and at the same time providing the undergraduates with the possibility of introducing and discussing new data.

4. Enhancing student critical thinking skills in the ESP course

The forming and enhancing the students' critical thinking skills in the present ESP course in the spring term 2021 was based on the three stages system of J.L. Steele, K.S. Meredith and C.Temple [16]. The strategy includes evocation, realization of meaning and reflection. Within this system, different skills are successively enhanced: identification and recall of the information on the specific theme, selection of facts and ideas, analysis and synthesis, evaluation through developing and presenting own ideas and opinions.

Studying the "New technologies" theme started with the introduction of the text about the most rapidly evolving computer spheres which according to the coursebook are nanotechnology,

Table 1. Studying the "New Technologies" theme within the blend.

	Theme 24 (4 hours)	Theme 25 (4 hours)	Theme 26 (4 hours)
In-class activities	Reading for detail, practising reading skills, speaking and writing activities, grammar revision	Watching videos, carrying out the pre- and post-watching activities	Giving and evaluating the presentations, argumentative speaking
Online activities	Listening, improving grammar skills	Searching for information, composing and designing a presentation	Writing an essay (with the focus on the video content critical analysis)
Teacher's role	Introduction into the theme, the discussion encouragement, integration of critical thinking tasks, eliciting grammar and vocabulary	Guidance on information search, on its analysis as well as on ways of presentation of own ideas	Presenting contradictory information, discussion facilitation, speaking and creative writing encouragement, outcomes consolidation

artificial intelligence, ubiquitous computing and devices and the smart home technology. The main in-class and online activities as well as the teacher's role while studying the "New Technologies" theme within the blend are presented in Table 1. At this stage, the teacher's role was to elicit the background knowledge from the course participants, to encourage them to share and interchange eclectic news and novelties from their prospective professional area. The English language aspect was also enhanced: while doing the unit tasks the students got familiarized with the new vocabulary and revised the ways of talking about the future. The first of three stages corresponded with the challenge phase of the critical thinking skills improvement concept. The information from the IT sphere provided by the undergraduates themselves was processed, new vocabulary was acquired, motivation for the further theme researching was enhanced. The task for the independent learning part of the blend was to analyze the prospects of the specified computer technologies and to rank them in accordance with the current human needs. The undergraduates had to explain their choice of the first positioned technology using the talking about the future constructions – in what way the certain IT sphere would be more valuable and useful for people in the next decade than the rest of the options from the coursebook. The in-class discussion revealed that most students had chosen the artificial intelligence sphere as the most significant one.

Thus, the second stage of the critical thinking skills forming (realization of meaning) was on. The teacher's role was to direct the students' perception and to keep them focused and motivated. The undergraduates independently processed and analyzed the provided information and put their effort into substantiating their vision of the future trend usability. In accordance with the students' choice (and namely the impact of artificial intelligence in everyday life), two videos were demonstrated: Murata Promotional Films displaying the Murata Boy and Murata Girl robots as well as the video about the Murata Cheerleaders (a squad of robotic ball-mounted cheerleaders) performance [17].

After that, technical films revealing the most important design details were shown and the robots' specifications were studied. The task for the students was to analyse the specifications and to list the Murata robots' properties (like balancing,group maneuvering and joint operation, ability to detect and avoid obstacles,ability to move in different directions) which could be employed in every day life and work routine. The highlighted English language aspects were speaking about abilities and expressing purpose. The task for the independent learning part of the blend was to find similar promotional videos demonstrating cutting-edge robots' abilities, impressive robots' utilization or the breaking news video spots from the AI sphere.

The third stage of the critical thinking enhancing system comprised reflection. The students had to appraise, to prioritize, to decide and to conclude when the videos were presented by their fellow students. Three selected as the most educational videos about robots were chosen as demonstrating the most prospective and wanted in the nearest future robots. The Atlas robot (make of Boston Dynamics) is able 'to maintain its balance through a variety of rapidly changing, high-energy activities' [18]. The human-like robot Ameca from Engineered Arts looks like a person and is able to interact with people expressing emotions [19]. The third robot is a companion for pets Rocki Robot (remote tentacle-headed cat and dog bot) from Rockybot.ai. The course participants explained their choice with the Covid-19 outbreak consequence consideration. In the future, people would increasingly need the practicality of robots capable to move and transport both heavy and fragile things over long distances and to avoid traffic congestions, able to deliver parcels quickly and carefully. Secondly, people tend to withdraw from interpersonal interaction: more and more loners would need a communication partner, that is amenable to control. Thirdly, being busy or away from home, people want to be sure that their pets are taken care about and they do not feel lonely or bored. Again, in terms of English language enhancing, in speaking and in writing tasks constructions for expressing purpose were focused on. The new language aspect was language means for making assumptions.

The consolidation of the "New technologies" theme was based on watching one more video. The task for the independent learning mode was to write an essay after watching in class the videospot from Bosstown dynamics [20] demonstrating a robot having a task to catch a box and to throw it back at people. In the process, two men prevented the robot from accomplishing the task in more and more violent way. People pushed the robot, hit it with a hockey stick, and even shot it with a gun. At first, the robot was concentrated on its mission, but gradually changed its behavior: first, it avoided the strikes, then it started to defend itself, and, finally, the robot attacked one of the aggressive men and gained the control of the gun and of the people. The contradictory and impressive content encouraged the students to speak up in their essays for the robot, to suggest strict human-robot interaction regulations or to predict the robot uprising in the future. Not a single student decided to justify the men. There were also essays suggesting that the robot had been programmed to fight back in respond to specific human actions. Imperatives of different obligation degree and constructions with modal verbs for permission, obligation, prohibition and necessity were widely used by the essays' authors.

Unfortunately, not a single viewer noticed that they had been shown not another promotional video from Boston Dynamics, but a staged fake video from Bosstown Dynamics in which all the Atlas robot's movements were performed by an actor and perfect computer-generated imagery was applied. The VFX before and after reveal video was shown which provoked a spirited discussion among the students about the prejudices against artificial intelligence which influence people's perception of robots' advantages and faults and prevent critical information analysis. Thanks to the parody video demonstration students were once more reminded some of the critical thinking principles and namely questioning the source of facts, gathering complete information, looking for hidden assumptions and biases, questioning the conclusions and examining the big picture.

Within the in-class activities of the last theme "New Technologies" (themes 24, 25 and 26) an experiment on students' ability to quickly progress in mastering critical thinking tests similar to the tests given by potential IT-companies' to their job applicants was conducted. It was a critical thinking test which is actually a pretest designed by L.Starkey and was retrieved from her book 'Critical Thinking Skills Success in 20 Minutes a Day'. It is a 30 multiple-choice question test without any time limitations which helps readers to determine critical thinking weaknesses and point them to the lessons in the book that cover the skills they need to work on [21]. Within the in-class mode of the blend in theme 24, 25 students of the second study year majoring in Computer Science were announced that they were going to do a critical thinking test in English language, and a brief instruction on circling the most reasonable selection (a, b, c or d) was circulated. Each student was given a test sheet, a blue ball pen and a separate sheet of paper to record their answers. When all the answer sheets were handed in, the teachers checked the answers without marking the correct answers on the students' sheets and recorded the results.

At theme 25 class, the answer sheets were given back to their holders accompanied with the test sheets and green ball pens. Neither the results of the pretest nor the questions' explanations were provided. A detailed explanation on how to accomplish critical thinking tests effectively followed. The students' attention was drawn to the recommendation to read the questions thoroughly and to try to determine the critical thinking aspects highlighted in them. Before answering the pretest questions the students should determine if for example deductive or inductive reasoning was implied, or, for instance, if skills in recognizing a problem or in troubleshooting were tested. Then the students were suggested to circle whether the same or the different answers with their green pens. On the second attempt completion, the procedure of results recording without notifying the students was repeated.

For the third time (at theme 26 class), the students were given their answer sheets, the test sheets and red ball pens. They were suggested to participate in a translation of the questions and the provided answers into Ukrainian language and simultaneously alter their test answers with the red colour ball pens if they consider it reasonable.

After the test was translated and the improvements were done by the students in their answer sheets, the correct answers to the pretest results were explained by the teachers and discussed in the group and the results of all the three attempts were analysed. The experiment has revealed that the average result of the group after the first attempt has been 63 percent (19 questions of 30 have been answered correctly). The explanation of the principles of the pretest accomplishing has increased the group's average achievement up to 79 percent (24 correct answers). The third attempt (the translation of the pretest in the students' mother tongue) has demonstrated the insignificant advance – 86 percent (26 correct answers). The group discussion of the pretest questions and the results has revealed that the most students have had no difficulties answering the questions concerning emotions and persuasion techniques. On the contrary, cause and effect confusing has been one of the most common errors of the students.

The students themselves have been intrigued with the experiment procedure, and afterwards have studied their own colour marks alterations (mostly, for better) on their answer sheets with great attention. The experiment has revealed that all the students have been able to deduce correct answers to situations based on recognizing and defining a problem, on persuasion and manipulating; the most difficult tasks like causal arguments or deductive reasoning from two premises are confusing and wearisome, therefore the strategies on how to deal with the questions highlighting them need to be provided.

As a part of the independent learning mode of the blend the students have been suggested to read the mentioned above book by L. Starkey and to present a report on the most difficult aspects of the training critical thinking skills tests provided in the book's practice section. Three students have shared their experience in learning the test strategies and self-testing with the group, having pointed out that each attempt of the next tests had made it easier for them to comprehend the principles of the critical thinking and to successfully take tests designed to establish the critical thinking skills.

5. Conclusions

In order to prepare the present computer science undergraduates for their successful career progression, the 21st Century Skills should be formed and improved in the prospective IT specialists. The English for Specific Purposes course is an effective launching environment where most skills could be inculcated in the young people willing to build their career within English speaking companies. Teaching the course participants perceive, process and reproduce information concerning their field of expertise in the decent way (in fluent written and oral English) is inseparably linked with teaching the young people critical thinking. Within the blended English for Specific Purposes course where the teachers are rather facilitators and most professionally oriented cutting-edge information is provided by the students themselves, the course participants are trained in carrying out the efficient information analysis and IT product evaluation. The students' ultimate task is to give their opinion about the mentioned above existing products and to voice their utilization suggestions. Such learning strategy supports students on their critical thinking evolving: from their ability to interpret, to appraise, to prioritize and to evaluate the information, the ability to decide, to conclude, to compose and to originate as well as to present new ideas in English is gradually formed and enhanced.

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Personal e-Learning Environment of the Maths teacher' online course as a means of improving ICT competency of a Mathematics teacher

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Personal e-Learning Environment of the Maths teacher' online course as a means of improving ICT competency of a Mathematics teacher

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Abstract. The paper studies the issue of increasing the ICT competency of a Maths teacher. The study analyzes the concept of ICT competency of a Maths teacher and considers the possibilities of its formation in different countries. One of the ways to increase the ICT competency of a Maths teacher is to use the "Personal e-learning environment of the Maths teacher" online course. The authors describe the model of the developed course, which is based on the ADDIE model and takes into consideration the key activities of a teacher. The experiment, conducted among master's students majoring in "Secondary education. Mathematics" showed the positive effects of the developed course on the level of their ICT competency. The redistribution of the percentage of the students towards normative and high levels of ICT competency formation was observed.

1. Introduction

1.1. Problem statement and its topicality substantiation

In the current circumstances of the global spread of distance learning, the problem of teachers' awareness of various information and communication tools is increasingly growing in importance. Their use by a present-day teacher is closely related to the selection of Web-tools for creating their own Personal Learning Environments (PLE), which provides a variety of activities. Thus, a Maths teacher, in particular, should not only organize students' learning activities but also search for information, conduct research, analyze and statistically process information, perform calculations, publish research findings, present reports and lectures, collaborate with other colleagues, and more. All this entails the need to constantly train teachers and form their ICT competency.

1.2. Analysis of the latest research and publications

Several studies have been devoted to addressing certain issues of the problem of Maths teachers' ICT competency (UNESCO [1], Kaiser and König [2], Jusoh et al. [3], Cetinkaya, Erbas, Celikdemiret al. [4]).

Thus, the United Nations Educational, Scientific and Cultural Organization (UNESCO) in partnership with leading industry organizations and experts from different countries developed "ICT Competency Framework for Teacherss" recommendations [1]. They include 18 competencies that are structured in accordance with six aspects of professional teaching activities (understanding the role of ICT in education policy, curriculum and assessment, teaching practices, application of digital skills, organization and management of the educational process, professional development of teachers) and three levels of applying ICT for teaching purposes (acquisition of knowledge, advancement of knowledge and construction of knowledge). The underlying idea of developing the above-mentioned competencies is that teachers who possess a sufficient level of competencies to use ICT in their professional activities will be able to ensure high quality of education.

In this regard, both foreign and Ukrainian researchers mostly consider the issues of forming ICT competency of future teachers in the process their training. Thus, Kaiser and König [2] provided an overview on the current knowledge derived from empirical research on the structure of the professional competence of teachers and competence development during teacher education. Jusoh et al. [3] highlighted dimensions of the impact of mathematics teachers' competencies on the level of their creative teaching practices. For this purpose, the authors propose to include information and communication technology (ICT) to the Primary School Integrated Curriculum and the Integrated School Curriculum.

However, the continuous improvement of Web-technologies necessitates the formation of ICT competency not only of future teachers but also the continuous professional development of those teachers who already work in schools and higher education institutions. Accordingly, Cetinkaya, Erbas, Celikdemiret al. [4] found what a group of experts involving mathematics teacher educators and representatives of educational non-governmental organizations think about the competencies a Maths teacher educators should possess. The authors note that the matter of teachers' professional development, in particular their ICT competency, was quite controversial. It is ascribed to the fact that one group of the researchers attributed it to the competency area "Teachings", and the other group – to "Service to the Society". According to Petukhova and Spivakovskyi [5], Petrenko [6], this was entailed by the fact that ICT competency is an integral characteristic of a personality, which affects all teacher activities. Therefore, Vlasenko et al. [7], Morse et al. [8] proposed to tap the selection of Web tools to fill the PLE of Maths teachers on the basis of their activities.

Consequently, the need for the continuous formation of ICT competency of a teacher, including the one of a Maths teacher, is beyond dispute. One of the best ways to address this issue, according to the researchers (Malhotra and Goyal [9], Broderick [10], Heap [11]), are online courses that will help teachers navigate the space of Web-technologies and level up their ICT competency.

That is the reason why there have recently been appearing more and more courses that offer teachers to improve their skills in the field of information technologies. Thus, Coursera platform offers teachers a "Learning to Teach Online" course [12], which aims to train the teacher on how to improve the design of a course with the aid of the Internet technologies. Ukrainian Catholic University developed the "E-Didactics and Blended Learning" course [13], the purpose of which is to provide information on the possibilities of teaching courses in the blended format. Proposed by from Ukrainian teachers, the "Blended Learning: Recipes – Simple and Tasty!" online course [14], hosted on the Blended Learning Club platform, is intended for those who want to diversify their teaching practices and modernize methodological approaches to developing training courses. Maastricht University (Netherlands) developed the "Problem-Based Learning: Principles and Design" course [15], during which the users practice applying tools that facilitate problem-oriented learning. The course developers provide an overview of online tools, share recommendations on the emotional inclusion of students in the learning process through social networks, creative tasks and mini-series.

Therefore, the idea of developing an online course for teachers to raise their awareness in the field of Web-tools is relevant. But, as stated by the authors of the "Eduget" platform [16], having a good idea is not enough for an online course to be a success. The whole host of factors that will interest the audience and encourage them to take the course should be considered. To ensure these factors when developing an online course, according to Krainer et al. [17], a model is needed that will be based on the needs of a teacher, particularly on all types of his/her activities.

As noted by Morrison [18], the online course model is a tool that describes the structure of the course, guides the user to the topic, removes distractions and ensures focus. The author points out that there are many models for designing curricula, but there are only a few that are specific to online designing of courses. The most well-known traditional models for developing online courses are the ADDIE (*Analysis, Design, Development, Implementation*, and *Evaluation*) principles [19], Dick Carey and Carey [20], and Rapid Instructional Design [21].

ADDIE is best considered as a classic representation of instructional design principles; its acronym associated with the five key principles of course design: *Analysis, Design, Development, Implementation*, and *Evaluation*.

Dick Carey and Carey Model [22] is a systematic model of instructional design, first introduced in 1978. It is sequential in nature similar to the ADDIE model. The model assumes the learner is active in the learning process, integrates the learner needs, skills and learning context into the design. It is a well-researched model that relies heavily on theoretical principles of learning, which no doubt is why it is a respected and widely implemented model in higher education.

Instructional Design Model for Online Learning (IDOL) [23] draws from the ADDIE principles, and the Dick, Carey and Carey model. It's perhaps best described as a "framework", since the authors of IDOL suggest it be used in conjunction with another design models, not as a replacement for. It presents 24 pedagogical dimensions for consideration during the design process.

Despite the prevalence of applying traditional models for online training courses, according to Morrison [18], what is required for a specific course that promotes the professional development of an adult and a professional is its specific flexible model of educational design. The researchers point to the need for a fresh approach to supporting targeted training of HEI teachers and creating a model that will help remove barriers to improving their ICT competency.

That is the reason why the purpose of our paper is to present a flexible model for an online course aimed at shaping a Maths teacher's ICT competency. Such a model, in our view, should take into account traditional models, but be specific to HEI teachers, i.e. be built on teachers' activities.

2. Method

As a basis for the development of the course we took a five-step ADDIE Model strategy (figure 1). This model of a systematic approach is best suited for the students' active participation in the learning process.

Over time, the content of each step (Analysis, Design, Development, Implementation and Evaluation) may change. Thus, in the future, not only the teacher but also the student will be the target audience. This will not only affect the first "Analysis" step but also change the further steps. In addition, the globalization of Web tools, the shift to engaging in Web 3.0

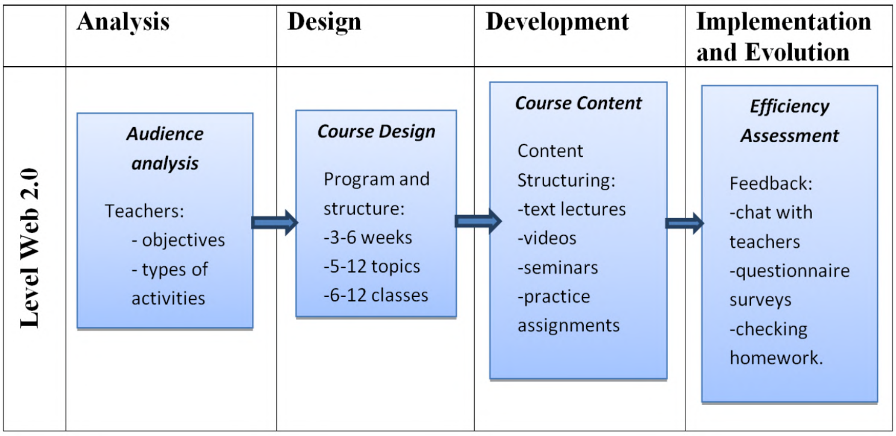

Figure 1. Model of the "Personal e-Learning Environment of the Math Teacher" online course.

learning, can accelerate the learning rates. Therefore, the duration of the course may shorten, and the content saturation may increase, which will entail adjustments to the "Design" and "Development" steps.

During the search phase of the study [7], Maths teachers were asked to independently select resources to fill their own PLE according to their activities, such as organizing the teaching process; searching for information; doing research, analysis and statistical processing of the information; doing the calculations; publishing popular science materials; publishing research papers; designing presentations collaborating; communicating; saving data. Based on this, we [7] developed a PLE model for a Maths teacher (figure 2).

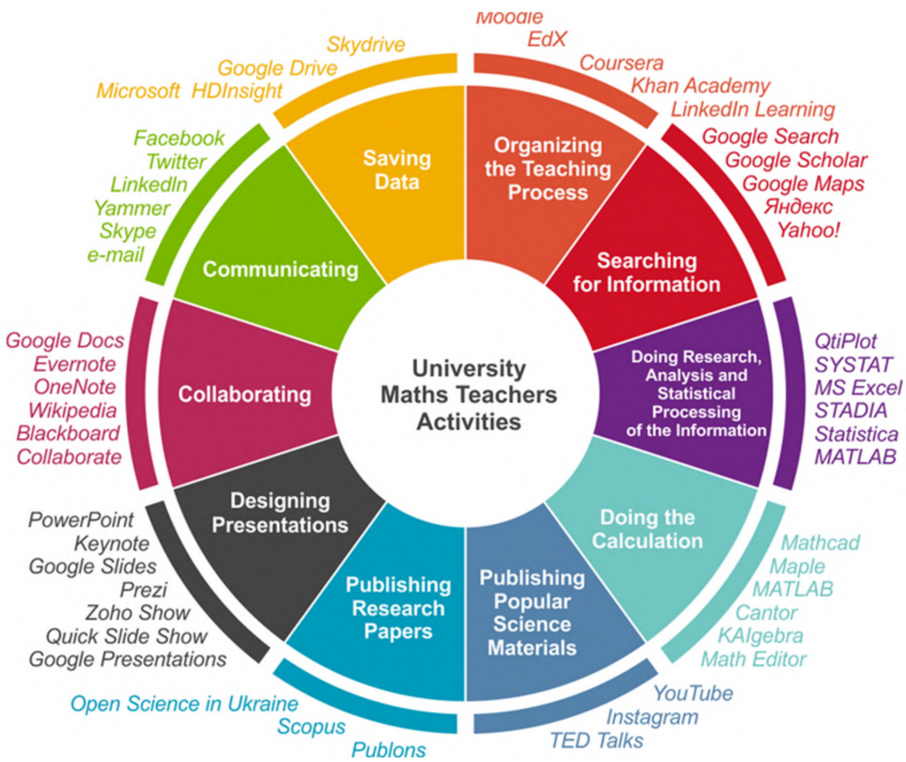

Figure 2. PLE for a Maths teacher.

This model at the present-day stage of the development of Web 2.0 technologies involves placing a Maths teacher in the center, which results in the teacher becoming the starting point for creating an external network of nodes. Web 2.0 tools are designed to help teachers improve their skills and level up ICT competency. In table 1, we analyze the various tools in terms of their functionality for the teacher.

Table 1. Functionalities of Web 2.0 tools for a Maths teacher.

Type of Activity	Web 2.0 Tools	Functionalities
Organizing the teaching process	Moodle, Classroom, Coursera, Khan Academy, EDX	Implementation of subject-subject relations between teachers and students
Searching for information	Google Search, Google Scholar, Yandex, Wikipedia	Rapid access to open information around the world
Doing research, analysis and statistical processing of the information	Systat, MS Excel, Stadia, Statistica, Matlab	Use of open, free e-resources around the world
Doing the calculations	Matlab, Mathcad, Cantor, Math Editor, KAlgebra	
Publishing popular science materials	Youtube, Instagram, Ted Talks	Sharing audio and video files via the Internet
Publishing research papers	Scopus, Publons, Open Science in Ukraine	Participation in professional scientific communities, Web content creation (articles and publications)
Designing presentations	Power Point, Prezi, Canva, Prezi, Zoho Show, Keynote, Google Slides	Web content creation (presentations, reports, audio and video clips)
Collaborating	Blackboard, OneNote, Evernote, Google Docs	Exchanging good practices and information, expanding the space in which communication takes place
Communicating	Facebook, Twitter, LinkedIn, Yammer, Skype, Zoom, e-mail	
Saving data	Skydrive, Google Drive, Dropbox	Storing large amounts of data, unrestricted access to them from any device

However, over the course of time, as Web tools evolve, we will see a shift to Web 3.0. The concept of Web 3.0 involves the creation of a reliable, flexible, optimized and at the same time "user-friendly" set of technologies and standards that would allow users, wherever they are, to identify any device nearby and create a network with it.

In this case, in the center of the PLE model, along with the teacher, there will be a student. And this is primarily related to the redistribution of roles between students and teachers because a teacher, trying to match up to the level of a student, begins to learn from the student, brings the student to the creation, dissemination, improvement of educational content. This way, the teacher will have to move from the formal transfer of knowledge to assisting the students in gaining it. The teacher becomes rather an advisor and a mentor for the student. Such changes will affect the modernization of the teacher's PLE and will require improvement of the "Design" and "Development" of a course due to the changes in the teacher's PLE.

The presented "Personal E-Learning Environment of the Maths Teacher" course [24] is designed to prepare the teacher for these changes (figure 3).

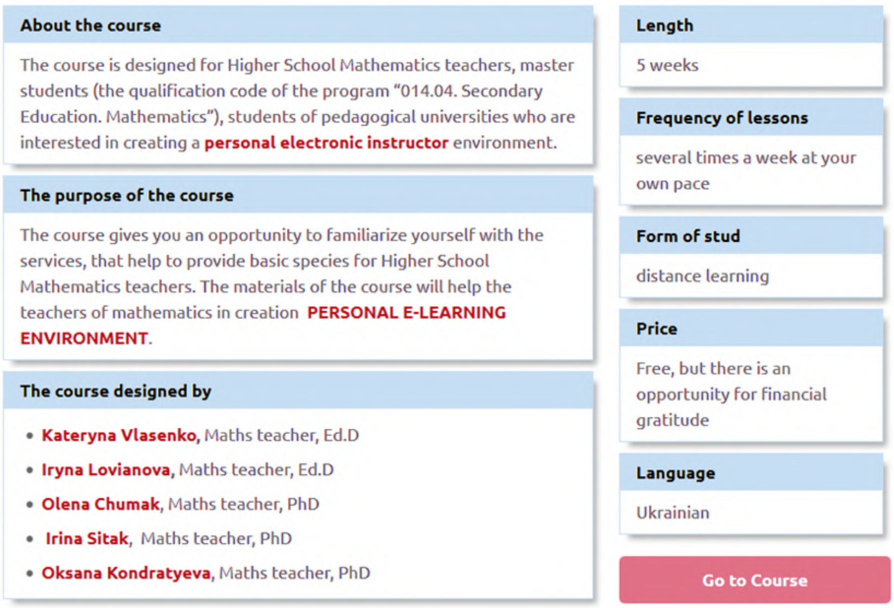

Figure 3. The webpage of the "Personal e-Learning Environment of the Maths Teacher" online course [24].

This online course is designed for 5 weeks to be worked through at the pace selected by a teacher. If desired, the user can pass the course faster, but the optimum pace is considered to be the one that provides for 2 lessons per week. Each lesson is packaged with a short text lecture, a video, a tutorial and a practice assignment. Gradually working out the class tasks, the teacher masters various Web 2.0 tools. Ranking of Web 2.0 services and their distribution in accordance with the types of teacher activities provides for the development of useful PLE, improves the level of Web tools mastery, helps to increase teachers' ICT competency.

3. Results

The experiment involved master's students majoring in Mathematics in Donbas State Engineering Academy, Kryvyi Rih State Pedagogical University, Berdyansk State Pedagogical University, a total of 50 volunteers. At the beginning of the experiment, the participants were randomly split into control (CG) and experimental (EG) groups. In the control group, 26 students studied the "Methods of Teaching Mathematics in a Specialized School (MTMSSh)" discipline following the traditional university program. In the experimental group, 24 students when studying MNMSH took the “Personal e-Learning Environment of the Maths Teacher” online course [24].

The indicators for the effectiveness assessment of the developed course were the levels of the ICT competency formation. Through the analysis of the scientific literature [7], [25], 4 levels of the ICT competency were differentiated: very low, elementary, normative, high. To determine the higher education seekers’ awareness about the use of various Web 2.0 tools, we applied special testing [26]. It included questions, associated with information access and management, information creation and presentation, problem-solving, decision-making, communication, creative expression and empirical reasoning. Respondents who received less than 30% of positive responses were classified as very low. Respondents who scored 30-50% – Elementary; 50-70% – Normative. Respondents had a high level, answering more than 70% of the questions. The analysis of the entrance level of the students’ ICT competency showed no significant difference between the levels of its formation in EG and CG students (table 2).

Table 2. The distribution of the respondents by the levels of ICT competency formation at the beginning of the experiment.

Level Groups	Very low	Elementary	Normative	High
EH, 26 persons	5,5%	54%	19%	21,5%
KH, 24 persons	5,9%	52%	20,2%	21,9%

The graphical representation of the results is shown in figure 4.

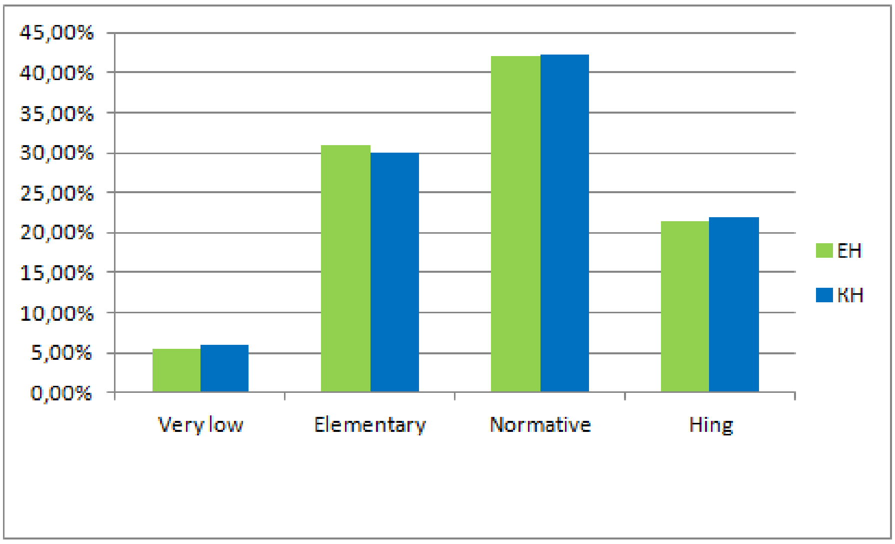

Figure 4. The distribution of the CG and EG students by the levels of ICT competency formation (at the beginning of the experiment).

At the end of the experiment, CG and EG students did the test again [26].

The results of the final assessment of the experimental and control groups are presented in table 3.

Table 3. TThe distribution of the respondents by the levels of ICT competency formation at the end of the experiment.

Level Groups	Very low	Elementary	Normative	High
EH, 26 persons	3,5%	36,5%	35,8%	24,1%
KH, 24 persons	4,9%	48,7%	23,5%	22,9%

As can be seen, at the end of the experiment, in EG we observe the redistribution of the percentage of students towards the normative and high levels. The overall increase was 19,9% compared to 4,3% in CG.

Thus, at the end of the experiment, there was an increase in the normative level of the ICT competency formation in EG by almost 16,8%, while with the CG students this level increased only by 3,3%. The number of course users having a high level of ICT competency in EG increased by 2,6%, whereas in CG – only by 1%. The graphical representation of the results is presented in figure 5.

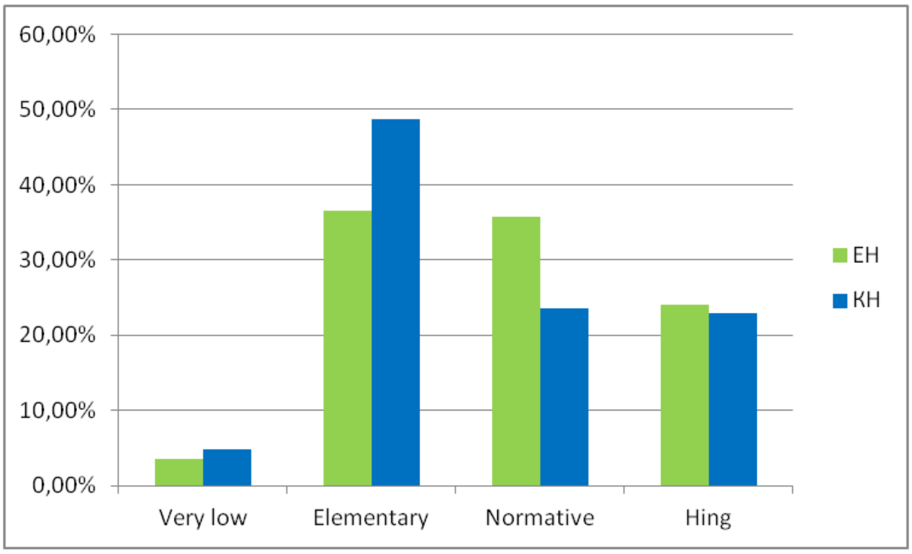

Figure 5. The distribution of the CG and EG students by the levels of ICT competency formation (at the end of the experiment).

4. Discussion

The search for approaches to the development of all-age students' ICT competency raises broad interest in all countries of the world. Thus, Jusoh et al. [3] analyze the experience of reforming education in Malaysia through the transformation of the Primary School Integrated Curriculum and the Integrated School Curriculum. The curriculum was complemented with such components as creativity and innovation, entrepreneurship and information and communication technology (ICT). However, as the Australian Curriculum Assessment and Reporting Authority noted [26], since the developed economies and societies increasingly rely on workers' and citizens'

ICT competency, and while schools already employ technologies in learning, they still need to increase their effectiveness significantly over the next decade.

This is agreed on by the Ukrainian researchers Morze et al. [8] who highlighted the formation of students' ICT competency on the basis of the TOTE model. The TOTE model accords to the proposed stages: 1.Test: determine the current state of the ICT competence of secondary school graduates; 2. Operate: the development of an ICT competence model of students in learning computer science; 3. Test: students' ICT-competence formation re-assessment; 4. Exit: recommendations for ICT competence forming. The researchers proposed a model for forming high school students' ICT competency in the process of teaching IT. Cetinkaya, Erbas, Celikdemiret al. [4], when studying the Turkish education system, noted that the issue of further teacher training, in particular their ICT competency, needs special consideration not only in secondary school but also while acquiring higher education. This opinion is supported by the research by Kaiser and König [2], who study the development of teacher competence during the transition from teacher education to teaching practice.

Therefore, ICT competencies should take a leading place among the other teacher competencies. And their formation should be continuous at all levels of education: at school, in higher education, and then during teaching activities. This is linked to the constant development of ICT technologies and the future transition from Web 2.0 to Web 3.0 resources. A universally applicable way to develop ICT competencies, according to Malhotra and Goyal [9], Broderick [10], Heap [11], are online courses that can be used both in training future teachers in graduate schools and after they are employed.

The experience of the"Eduget" platform authors [16] confirmed our view of the usefulness of developing the "Personal e-Learning Environment of the Maths Teacher" online course [24] as an effective way to increase Maths teachers' ICT competency. We folloed their recommendations into account and applied a set of factors that will interest the audience and encourage them to take the course. We also took into consideration the opinion of Krainer et al. [17], and while designing the online course presented the model, based on the teachers' needs, in particular, on all types of their activities. Due to this, the developed online course is based on the ADDIE Model. The application of this model provides for flexibility of the educational process, through which a higher education seeker is able to independently set the pace of passing the course and completing the assignments. In the future, this model can be transformed to master Web 3.0 resources. The results of the experiment among master's students showed a positive effect of this course on the formation of ICT competency of future Maths teachers. Besides, positive feedback was received from already working Maths teachers. However, in the future, there may be scope for conducting the experiment among working teachers, in order to test the effectiveness of the course on the more experienced audience.

5. Conclusions

The analysis of the pedagogical literature suggests that the development of online courses in the learning process is at the height of its popularity. The use of online courses is an effective means of increasing the ICT competency of both teachers and seekers of higher pedagogical education. The analysis of the results of the questionnaire survey among HEI Maths teachers confirmed their insufficient level of ICT competency and the willingness to increase it with the help of our "Personal e-Learning Environment of the Maths Teacher" online course.

The placement of the course on the "Higher School Mathematics Teachers" platform provided free access to the course materials. The development of the course model, its structure and topics should be based on the analysis of Maths teachers' activities, the existing educational resources that support online education.

The discussion on the forum ensured increasing in the amount of the submitted educational material, the range of forms of presenting educational content. The results of the experiment among master's students and the analysis of the opinions of the forum participants confirmed the possibility of the course being used by Maths teachers in higher school.

Among the directions for further research, we see the introduction of the developed online course not only in the process of teaching master's students but also in the process of improving ICT competency and professional development of working Maths teachers.

We are grateful to the students who took part in the experiment, the teachers who participated in our questionnaire survey and thus helped us in conducting the research.

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The impact of psychological and learning training on educational motives and reflective skills of future IT specialists

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Abstract. Nowadays, there are a lot of psychological and pedagogical research aimed to explore students' individual characteristics and how to take them into account in educational process, as well as to develop new teaching techniques. In this study, we focus on future IT specialists' internal motivation to continue education and training, internal motivation for professional activity as a software engineer, and reflective skills. We consider the impact of psychological and learning training on educational motivation and reflective skills of university students. We present pedagogical technique which involves motivational training, training exercises, and learning training. In particular, we give a brief description of author's learning training on "NoSQL databases: MongoDB and ASP.NET MVC". The results of pedagogical experiment conducted to evaluate efficiency of this technique are presented. In experimental work 405 higher education students majoring in 121 Software Engineering, 122 Computer Science, 123 Computer Engineering took part. Based on statistical processing of empirical data, we made a conclusion about potency of our technique.

1. Introduction

The development of the information society, the formation of open knowledge societies, the globalization processes cause the growing need for highly qualified IT specialists who can produce effective means of access to information, its accumulation and processing. There are high requirements for these workers: from having thorough professional knowledge in computer science and software engineering to a range of practical skills in software development as well as communication, management, reflective skills, responsibility, independence, professional mobility, readiness for permanent and advanced training.

Universities as centres of high-quality fundamental education, which is based on the principles of competence and student-oriented approaches, play the leading role in meeting the demand for such specialists. The semantic centre of this activity is now a student. That is because, in the context of increasing the importance of the ideas of a society of sustainable development and lifelong learning, human is the main social value. At the same time, universities are designed to meet the needs of other stakeholders, including the labour market and academia. Among such urgent requests is the need to implement educational programs of a shortened cycle of professional training of future IT specialists. Their purpose is to provide specialists with the opportunity to obtain a bachelor degree based on a junior specialist or a junior bachelor degree. The social significance of this task is related to the need of IT companies in the rapid training of highly qualified workers, as well as the person's need to improve skills or master a new speciality, to determine his/her own educational and professional path.

There are some contradictions that hinder the efficient professional training of future IT specialist, in particular future software engineers, namely:

- between the requirements for the professional level of IT specialities graduates and insufficient motivation of higher education students to study and improve their skills;
- between the educational needs of students and the limited ability to build individual educational trajectories with a combination of different forms of education, including non-formal one, at universities;
- between the availability of students with professional competences formed during the previous level of education, and the IT bachelor's curricula content at universities;
- between the need to comply with the standards of Ukrainian higher education at the bachelor's level and the limited period of study.

To overcome these contradictions, we have developed teaching technique to improve professional competencies and to enhance the learning outcomes of future IT specialists. This technique contains means for development of motivational, cognitive, operational, communicative, and reflective individual spheres. In this article, we focus on forming of students' academic motivation and reflective skills by the means of psychological and learning training.

The article aims to present authors' approach to use psychological and learning training in IT education and the results of an experimental examination of its impact on students' educational motives and reflective skills.

2. Literature review

To develop our technique and ways to implement it in the process of future IT specialists education, we reviewed the scientific publications [1–11] and psychological and pedagogical books [12–17] on the problems of human *motivation*. Let's focus on some aspects of this phenomenon.

According to Rean, the motive is "the inner motivation of the individual to a particular type of activity (activity, communication, behavior), associated with the satisfaction of a particular need" [16, p. 89], and "a set of stable motives that have a certain hierarchy and express the orientation of the individual" forms the motivational sphere of the individual [16, p. 90].

As Bakshaeva and Verbitskiy noted, any human activity is polymotivated, i.e. guided by many motives, it is impossible to identify individual motives, especially in educational activities, so the problem of forming cognitive, professional and other motives is extremely difficult [12, p. 93]. The phenomenon of polymotivation is manifested when within one physical behavior of a person several activities are psychologically carried out, each of which corresponds to its motive [3, p. 106].

Extremely interesting is Klymchuk's opinion that according to modern post-classical scientific views "the motivation of the individual ceases to be a set of biological or social needs, a hierarchy of values" [14, p. 7], it turns into "a permanent process of constructing motivation, explaining to oneself the reasons and goals, meanings and values (motivational narrative)" [14, p. 7].

There are two main types of motivation: extrinsic and intrinsic. Ryan and Deci in [8] notes:

- "Intrinsic motivation is defined as the doing of an activity for its inherent satisfactions rather than for some separable consequence." [8, p. 56];
- "Extrinsic motivation is a construct that pertains whenever an activity is done in order to attain some separable outcome." [8, p. 60].

According to Ilin, intrinsic motivation is “the process of forming a motive with reliance on internal factors (needs, urges, desires)” [13, p. 344].

The main theme of Ryan and Deci article [9] is self-determination theory (SDT). They consider SDT as a framework for understanding factors that facilitate or undermine intrinsic motivation, autonomous extrinsic motivation, and psychological wellness. The authors make a conclusion that both intrinsic motivation and well-internalized forms of extrinsic motivation has a positive impact on educational levels. Moreover, there is a dynamic link between teaching style and student motivation.

Keller in his work [17] presents the ARCS (Attention, Relevance, Confidence, Satisfaction) model of motivational design which is aimed to improve “students’ motivation to learn, employees’ motivation to work, people’s motivation to pursue a chosen career path.” [17, p. 22]. Also, the author describes in details the main stages of motivational design: (i) identifying motivational problems; (ii) identifying motivational goals and tactics; (iii) integrating motivational and instructional strategies. Tools to support motivational design (worksheets, surveys, checklists) are very useful and should be applied in educational process.

Scholars discuss the impact of academic motivation on different processes, such as: on higher education students’ intention to drop out [7]; on students social integration during the first year of higher education [5]; on students perceive their learning environment [2], etc.

Based on these and other research, in our study we focus on the formation and development of students’ intrinsic motivation. We consider two its aspects: internal motivation to continue education and training, as well as internal motivation for professional activity as a software engineer.

The other difficult phenomenon for our research is *reflection*. Psychological and pedagogical issues of *reflection*, *reflexivity*, and *reflective skills* are considered in scientific publications [18–28].

In [29, p. 278] reflection is defined as “a person’s awareness of their own actions, their root causes and consequences, self-knowledge, which reveals the specifics of the spiritual world of man, introspection.”

Marshall proposes the next definition: “Reflection is a careful examination and bringing together of ideas to create new insight through ongoing cycles of expression and re/evaluation.” [27, p. 411].

D’Cruz, Gillingham, and Melendez in their work [21] considers three different meanings of the concept of reflexivity. The first variation is interesting for us because it is focused on “reflexivity as an individual’s considered response to an immediate context and making choices for further direction” [21, p. 75]. This meaning involves that individuals are able to process information and create knowledge to guide course of their own lives, and responsible for their choices, self-development and self-actualization.

Karpov in [25] designates such types of refection:

- *Situational reflection* provides direct self-control of human behavior in the current situation, comprehension of its elements, analysis of what is happening, an individual’s ability to correlate his/her actions with the situation and coordinate them in accordance with changing conditions and his/her own state.
- *Retrospective reflection* is manifested in a tendency to analyze past events and activities performed in the past. The subjects of this reflection are the prerequisites, motives, and causes of what happened; the content of past behavior, as well as its performance parameters and mistakes made.
- *Perspective reflection* correlates: with the analysis upcoming activities or behavior; planning; predicting probable outcomes, etc.

Gray in his article [22] gives a description of tools and processes for promoting critical management reflection, such as: storytelling, reflective and reflexive conversations, reflective dialogue, reflective metaphors, reflective journals, reflecting on critical incidents, repertory grids, concept mapping. We think that these means can be implemented for formation reflection skills, especially critical reflection and reflective thinking, of future IT specialists at universities. However, it is necessary to take into account some restrictions, eg. conversational tools are not widely used in IT education.

Engelbertink et al. in [23] present and discuss results of empirical research aimed to determine how university students reflect on five components of professional identity and at what reflection level (descriptive writing, descriptive reflection, reflection, critical reflection). These components are defined by Kelchtermans in [30], namely: self-image, self-esteem, task perception, job motivation and future perspective. We think that formation of professional identity in future IT specialists is extremally significant for their career and psychological wellness and is connected with academic motivation. So, it is expedient to use the proposed approach in next research.

Thus, we consider the reflective skills of future IT specialist as an ability to self-understand, analyze and evaluate yourself as an individual, a specialist, as a member of software developers team, as well as your own actions in the current situation, past and future.

3. Research results

We offer to use some methods of formation and development of students' internal motivation for obtaining higher education, professional development, professional activities, namely: training, motivation techniques, training exercises, meetings with IT professionals and others. Among them, training is the most difficult because it requires thorough preparation. In order to form professional competencies of future IT specialists, their educational motivation, and reflective skills we use the motivational, as well as learning training. It should be borne in mind that appropriate activities should be carried out systematically, both in the process of teaching certain disciplines and in extracurricular activities.

Training is "an organizational form of educational work, which, based on the experience and knowledge of its participants, provides effective use of various pedagogical methods, in particular interactive, by creating a positive atmosphere in the group, and aims to acquire skills and life competencies." [31, p. 15]. According to Fedorchuk, training is the most effective model of inclusion of the individual in interpersonal communication and activities aimed at self-knowledge, development, self-improvement of the individual [32, p. 12].

There are different approaches to definition of learning training. Thus, the researcher Bondareva considers it as an educational activity, during which "future specialists perform training exercises adapted to future professional activities, under the guidance of a teacher-trainer on the basis of specially prepared instructional materials meeting modern requirements for professional activity" [33, p. 90].

Conducting training involves the use of active and interactive technologies, organization of interpersonal and group communications. It should be focused "on the acquisition of social and professional experience, the development of professionally significant and personal qualities and abilities of students, the formation of general (universal, key) and professional competencies." [29, p. 278].

Our technique involves such elements: motivational training; training exercises; learning training. *Motivational training for future IT specialists.* Conducting this sort of training, we relied on Afanasieva's and Perelyhina's works "Training of professional motivation and self-awareness" and "Training of achievement motivation" [34], Klymchuk's and Horbunova's "Program for the Development of Internal Motivation of Youth Educational Activity" [15], elements of Fedorchuk's "Personal Growth Training" Program [32].

"Training for the development of professional motivation and self-awareness" by Afanasieva and Perelyhina [34] is designed for 4 days. During the first day, exercises are performed aimed at creating friendly relationships in the group and ensuring interaction, analysis of the past, analysis of goals and meaning of life. During the second day there is a study of the life and psychological time of group members. During the third day, students study themselves and their resources, analyze the personal value-semantic sphere, begin to prepare an essay of self-characteristics. Depending on the individual experience of the group members and the goals of the training, there are two options: self-characterization in the professional IT activity or self-characterization in educational activity. The last day of the training is devoted to the analysis of one's own social-role positions and the positions of other people. To this end, participants are invited to create an outline of fixed roles for other group members. The result of the training is the formation of abilities and focus on rethinking values. As part of the experimental work, this training was conducted over two weeks: two classes per week. The training methodology is not tied to a specific professional activity, so it is quite easy to adapt for a group of future IT specialists.

"The program of development of internal motivation of educational activity of youth" of Klymchuk and Horbunova consists of 8 stages and its' duration is 4 weeks [15, p. 80]. The program provides not only to create essays of fixed roles, but also to play them in life during the week.

Training exercises. In order to strengthen the internal motivation of future IT specialists, we use training exercises in classes that do not require much time, but allow to motivate students to activity, interaction and more.

For example, *the exercise "Ask - I answer"* [31, p. 37] can be used in the study of any discipline, especially during lectures. The content of the exercise is that each student or part of them, depending on the size of the group receives a card with a number and a question on the topic of the lesson. The teacher warns that in the course of the lesson it will be necessary to provide an answer. When a certain moment comes, the teacher asks: "Who has the card number N?" A student who has a card with this number voices the question and provides an answer. The exercise promotes concentration of the discussed material, accustoms students to fast and concise formulation of answers, motivates to educational activity during employment.

In order to create micro-groups to perform projects in laboratory classes, we use *the exercise "Puzzles"* [31, p. 42]. Students form a circle. The teacher then calls the number and they have to form groups with so many participants at random. The first two or three attempts are training, so that the participants move a little.

Learning training. Interactive technique "Snowball". This is the author's modification of the method given in [35, p. 82-86]. Its essence: to make a common definition, decision or goal, participants gradually combine their original atomic ideas. The technique allows to involve all students in the discussion, connect the group, but requires just a lot of time.

For example, the "Snowbal" technique can be implemented in the process of learning the concept of "inheritance" in object-oriented programming course. The main stages of the lesson:

(i) *introduction* - the lecturer explains the purpose, finds out whether any of the participants has experience in programming using inheritance (10 minutes);

(ii) *individual work* - participants write on sheets of paper 3 signs of the concept of inheritance based on their life, educational or professional experience (5 minutes);

(iii) *work in teams* - the lecturer divides the group into teams of 3 students each; teams formulate joint definitions from the participants initial ideas (10 minutes);

(iv) *work in small groups* - the teacher unites teams into mini-groups (2-3 teams); mini-groups formulate their definitions of inheritance (10 minutes);

(v) *final discussion* - mini-groups present their definitions, discuss them, the lecturer formulates the final definition (15 minutes).

Such work is quite long, but it contributes to the formation of students positive motivation, as it emphasizes the role of each participant in obtaining the final result.

The program of author's learning training on "NoSQL databases: MongoDB and ASP.NET MVC" was developed. The key problem of this training is the use of document-oriented databases. Its purpose is to form students' competence to develop such databases. This material is not included in the normative content of the discipline "Databases and Information Systems." Thus, the training is aimed at raising the professional awareness and educational motivation of higher education students, as well as it facilitates to develop their reflective skills. Training tasks are to acquaint students with the basics of document-oriented databases, to form skills to create and modify MongoDB databases, to show pros and cons of document-oriented databases. The duration of the work in auditory is 5 hours, 30 minutes are given for three breaks. Prior to the training, students should learn the basics of NoSQL databases and MongoDB.

The structure of "NoSQL databases: MongoDB and ASP.NET MVC" training is presented in the Table 1.

Based on the experience of implementation of motivational and learning training, we consider the following aspects should be taken into account to develop effective training for IT students:

(i) students already have some educational and professional experience, so the provisions of the andragogical approach should be taken into account;
(ii) training requires a significant amount of time for both the teacher-trainer and students, so this method should be used within the certification educational programs, in extracurricular time or if it is possible to take several classes in a row;
(iii) the content and activity of the training should be focused on the formation of clearly defined professional competencies and reflect the specifics of professional activity in the IT field;
(iv) programmers from enterprises should be invited to participate in training, who can reveal non-standard aspects of the problem.

4. Experimental data

4.1. Experimental design

The impact of psychological and learning training on educational motivation and reflective skills of future IT specialists was examined within the framework of pedagogical experiment. It was conducted during 2016-2019 at Ukrainian universities, in particular, Bogdan Khmelnitsky Melitopol State Pedagogical University. The experimental work was aimed to check the effectiveness of organizational and pedagogical conditions of the formation of future software engineers professional competences which were studying by the shortened cycle of training at universities.

The pedagogical experiment included ascertaining and formative stages. At the ascertaining stage, the initial level of educational motivation and reflective skills was examined. At the formative stage, developed technique was implemented in the experimental group. The empirical data were processed to determine the presence or absence of statistically significant differences between the control and experimental groups using the statistical methods, namely: Kolmogorov–Smirnov test (KS-test) and Fisher test (F-test).

We examined students' internal motivation to continue education and training, internal motivation for professional activity as a software engineer, as well as reflective skills. We considered that each of individual characteristics had 5 levels of forming, namely: low, critical, medium, sufficient, and high. To estimate students' internal motivation to continue education and training we used Ilina's "Motivation of study at higher educational institution" technique [13, p. 433-434]. To estimate students' internal motivation for professional activity as a software

Table 1. The structure of "NoSQL databases: MongoDB and ASP.NET MVC" authors' training

Duration (min.)	Tasks	Results	Methods
		Intro stage	
5	Acquaintance	Acquaintance with the training schedule	Trainer's speech
15	Formulation of expectations	Setting up for work. Awareness of goals	Exercise "Interesting participant" [31, p. 35]
10	Establishing the group's rules	Forming a safety atmosphere in the group	Brainstorming
		Main stage	
15	Mini-lecture "Database types"	Generalization of knowledge about database types	Mini-lecture
10	Warm-up	Removing fatigue	Exercise "Kapitoshka said" [36, p. 84]
15	Mini-lecture "MongoDB Opportunities"	Introducing students to the main features of MongoDB	Mini-lecture
10	Break	–	–
5	Setting up for group work	Unite groups to perform a practical task	Exercise "Puzzles" [31, p. 42]
60	Workshop "Creating a database"	Skills to develop a database using MongoDB	Workshop
10	Warm-up	Removing fatigue	Exercise "Bim-Bom" [36, p. 82]
10	Break	–	–
10	Activation of participants' activities	Setting for further work in groups	Exercise "Find a half" [36, p. 82]
15	Mini-lecture "How to choose a database to solve the problem"	Introducing students to approaches to choosing a database	Mini-lecture
20	Workshop "Choosing a database for the site"	Skills to choose the best methods of data storage taking into account the specifics of the task	Business game "Battle of the database"
10	Warm-up	Removing fatigue	Exercise "Who am I" [36, p. 84]
10	Break	–	–
		Final stage	
30	Reflection "Training results"	Analysis of acquired knowledge and skills	Exercises "Knowledge Network" [31, p. 45], "Complete the sentence" [31, p. 46]
15	Reflection "Participants about training and trainer"	Analysis of the results of training and personality of the trainer	Questionnaire of participants
10	Reflection "Trainer about the teams"	The most successful moments of training, evaluation of student work	Trainer's speech

engineer we used Gerbachevskiy's "The level of claims of the individual" technique [37, p. 303-308]. To estimate students' we used Karpov's and Ponomaryova technique of reflexivity diagnostics [25].

The general population was formed by higher education students of the first (bachelor's) level of specialties in the field of information technology. The sample was selected from the general population taking into account the following criteria: comparability of curricula in structure and content; similarity of content and educational results of selected disciplines of the cycle of professional training and modules; similarity of principles of admission of students to study (term of study, previous education, entrance examinations). Thus, 405 higher education students were selected to participate in the pedagogical experiment, majoring in 121 Software Engineering, 122 Computer Science, 123 Computer Engineering. This exceeds the minimum sample size defined above and ensures that the sample is representative. The number of control group (CG) was 207 persons. The number of the experimental group (EG) was 198 persons.

4.2. The ascertaining stage

An examination of students' internal motivation to continue education and training revealed the following: 46.38% of participants in CG (96 persons) and 42.93% participants in EG (85 persons) had low or critical level; 53.62% of participants in CG (111 persons) and 57.07% of participants in EG (113 persons) had medium, sufficient or high level (see Table 2). Thus, students generally understood the need to continue their education, to obtain a bachelor's degree and to learn further, and were sufficiently motivated to study.

Table 2. Students' internal motivation to continue education and training at the ascertaining stage

Level	Control group		Experimental group	
	persons	%	persons	%
low	29	14.01%	22	11.11%
critical	67	32.37%	63	31.82%
medium	72	34.78%	74	37.37%
sufficient	30	14.49%	28	14.14%
high	9	4.35%	11	5.56%
Total	207	100%	198	100%

An examination of students' internal motivation for professional activity as a software engineer revealed the following: 35.26% of participants in CG (73 persons) and 36.36% in EG (72 persons) had low or critical level; 64.73% of participants in CG (134 persons) and 63.64% in EG (126 persons) had medium, sufficient or high level (see Table 3). Thus, students were slightly more motivated to professional activity than to continue education.

An examination students' reflective skills revealed the following: 61.83% of participants in CG (128 persons) and 57.57% in EG (114 persons) had a low or critical level; 38.16% of participants in CG (79 persons) and 42.43% in EG (84 persons) had medium, sufficient or high level (see Table 4). Thus, students demonstrated the lack of ability to reflect on educational and professional activities.

Valuation of the empirical data. Checking the hypothesis about the absence of statistically significant differences between control and experimental groups was performed using KS-test and F-test:

Table 3. Students' internal motivation for professional activity as a software engineer at the ascertaining stage

Level	Control group		Experimental group	
	persons	%	persons	%
low	21	10.14%	18	9.09%
critical	52	25.12%	54	27.27%
medium	87	42.03%	75	37.88%
sufficient	33	15.94%	36	18.18%
high	14	6.76%	15	7.58%
Total	207	100%	198	100%

Table 4. Students' reflective skills at the ascertaining stage

Level	Control group		Experimental group	
	persons	%	persons	%
low	52	25.12%	42	21.21%
critical	76	36.71%	72	36.36%
medium	51	24.64%	53	26.77%
sufficient	21	10.14%	25	12.63%
high	7	3.38%	6	3.03%
Total	207	100%	198	100%

- null hypothesis H_0: there is no statistically significant difference between the samples;
- alternative hypothesis H_1: there is a statistically significant difference between the samples.

Critical value of KS-test is $\lambda_{cr} = 1.36$ for the level of significance $\alpha = 0.05$. Critical value of F-test is $\phi^*_{cr} = 1.64$ for the level of significance $\alpha = 0.05$. The results of testing these statistical hypotheses are given in Table 5.

Thus, the empirical data showed that students found mostly low and critical level of reflective skills and medium level of educational motivation. In this regard, we thought it was necessary to direct the educational process to strengthen the internal motivation of higher education students to professional activities as a software engineer, continuing education and training; formation of abilities to reflect on educational and production activities (reflective skills). In addition, statistical test shown that there were no statistically significant difference between control and experimental groups.

4.3. The results of the formative stage of the pedagogical experiment

An examination of students' internal motivation to continue education and training revealed the following: 72.47% of participants in CG (150 persons) and 81.81% of participants in EG (162 persons) had a medium, sufficient or high level; 27.54% of participants in CG (57 persons) and 18.18% of participants in EG (36 persons) had low or critical level (see Table 6). The most

Table 5. Results of valuation of the empirical data (ascertaining stage of the experiment)

Criterion	KS-test	F-test	Conclusion
Internal motivation to continue education and training	$\lambda_{emp} = 0.347$; $\lambda_{emp} < \lambda_{cr}$	$\phi^*_{emp} = 0.714$; $\phi^*_{emp} < \phi^*_{cr}$	Hypothesis H_0 is accepted.
Internal motivation for professional activity as a software engineer	$\lambda_{emp} = 0.307$; $\lambda_{emp} < \lambda_{cr}$	$\phi^*_{emp} = 0.724$; $\phi^*_{emp} < \phi^*_{cr}$	Hypothesis H_0 is accepted.
Reflective skills	$\lambda_{emp} = 0.429$; $\lambda_{emp} < \lambda_{cr}$	$\phi^*_{emp} = 0.865$; $\phi^*_{emp} < \phi^*_{cr}$	Hypothesis H_0 is accepted.

significant difference between CG and EG (-10.67%) was recorded at a sufficient level, i.e. the percentage of students with a sufficient level of educational motivation in EG exceeds a such percentage in CG.

Table 6. Students' internal motivation to continue education and training at the formative stage

Level	Control group		Experimental group	
	persons	%	persons	%
low	18	8.70%	12	6.06%
critical	39	18.84%	24	12.12%
medium	86	41.55%	70	35.35%
sufficient	49	23.67%	68	34.34%
high	15	7.25%	24	12.12%
Total	207	100%	198	100%

An examination of students' internal motivation for professional activity as a software engineer revealed the following: 76.82% of participants in CG (159 persons) and 83.83% of participants in EG (166 persons) had a medium, sufficient or high level; 23.19% of participants in CG (48 persons) and 16.16% of participants in EG (32 persons) had low or critical level (see Table 7). The most significant difference between CG and EG was recorded at medium (+9.27%) and high (-8.47%) levels, i.e. the percentage of students with the medium level of educational motivation in CG exceeds the same percentage in EG, and the percentage of students with a high level of educational motivation in the EG exceeds this percentage in CG. In addition, as at the ascertaining stage, students had a greater motivation to continue professional activities than to continue learning.

An examination students' reflective skills revealed the following: 65.22% of participants in CG (135 persons) and 77.27% of participants in EG (153 persons) had a medium, sufficient or high level; 34.78% of participants in CG (72 persons) and 22.73% of participants in EG (45 persons) had low or critical level (see Table 8). The most significant difference between CG and EG was recorded at critical (+8.98%) and sufficient (-11.50%) levels, i.e. the percentage

Table 7. Students' internal motivation for professional activity as a software engineer at the formative stage

Level	Control group		Experimental group	
	persons	%	persons	%
low	17	8.21%	10	5.05%
critical	31	14.98%	22	11.11%
medium	84	40.58%	62	31.31%
sufficient	57	27.54%	70	35.35%
high	18	8.70%	34	17.17%
Total	207	100%	198	100%

of students with a critical level of reflective skills in CG exceeds a similar percentage in EG, and the percentage of students with a sufficient level of reflective skills in EG exceeds a similar percentage in CG.

Table 8. Students' reflective skills at the formative stage

Level	Control group		Experimental group	
	persons	%	persons	%
low	21	10.14%	14	7.07%
critical	51	24.64%	31	15.66%
medium	75	36.23%	65	32.83%
sufficient	41	19.81%	62	31.31%
high	19	9.18%	26	13.13%
Total	207	100%	198	100%

Valuation of the empirical data. Checking the hypothesis about the absence of statistically significant differences between control and experimental groups was performed using KS-test and F-test:

- null hypothesis H_0: there is no statistically significant difference between the samples;
- alternative hypothesis H_1: there is a statistically significant difference between the samples.

Critical value of KS-test is $\lambda_{cr} = 1.36$ for the level of significance $\alpha = 0.05$. Critical value of F-test is $\phi^*_{cr} = 1.64$ for the level of significance $\alpha = 0.05$. The results of testing these statistical hypotheses are given in Table 9.

Thus, statistical test shown that there were statistically significant difference between control and experimental groups.

During the pedagogical experiment, the level of students' educational motivation and reflective skills in the control and experimental groups was determined using the indicator of the percentage of persons for each of the levels. Based on this, conclusions were made about the dynamics of these characteristics, as well as the effectiveness of the implementation of educational

Table 9. Results of valuation of the empirical data (formative stage of the experiment)

Criterion	KS-test	F-test	Conclusion
Internal motivation to continue education and training	$\lambda_{emp} = 1.565$; $\lambda_{emp} > \lambda_{cr}$	$\phi^*_{emp} = 3.239$; $\phi^*_{emp} > \phi^*_{cr}$	Hypothesis H_1 is accepted.
Internal motivation for professional activity as a software engineer	$\lambda_{emp} = 1.64$; $\lambda_{emp} > \lambda_{cr}$	$\phi^*_{emp} = 3.32$; $\phi^*_{emp} > \phi^*_{cr}$	Hypothesis H_1 is accepted.
Reflective skills	$\lambda_{emp} = 1.554$; $\lambda_{emp} > \lambda_{cr}$	$\phi^*_{emp} = 3.239$; $\phi^*_{emp} > \phi^*_{cr}$	Hypothesis H_1 is accepted.

technique. The dynamics of students' educational motivation and reflective skills in CG and EG was positive, i.e. the percentage of students with a sufficient and high level at the end of the formative stage of the experiment increased compared to the results of the ascertaining stage.

In particular, the percentage of participants with a sufficient and high level of educational motivation by the criterion of formation of internal motivation to continue education and training increased by 12.08% in CG and by 26.76% in EG; the percentage of participants with a sufficient and high level of educational motivation by the criterion of formation of internal motivation for professional activity of software engineer increased by 13.52% in CG and by 26.77% in EG. the percentage of participants with a sufficient and high level of reflective skills increased by 15.46% in CG and by 28.78% in EG. Therefore, the positive changes in the experimental group were more significant than in the control group. We explain these changes by the fact that our educational technique was implemented in the experimental group.

5. Conclusion

Nowadays, psychological and learning training are widely used in formal and informal education, especially in adult education. They have significant potential for improving of learners hard and soft skills. Considering this, we decided to develop pedagogical technique which involves motivational training, training exercises, and learning training, and then to examine its efficiency for IT education.

At the end of the formative stage of the experiment, a positive trend in the formation of students' educational and professional motivation and reflective skills was recorded in the experimental group due to the implementation of the developed educational technique based on using psychological and learning training. So, we can state that its implementation is effective and has a positive impact on the improving of motivational and reflexive spheres of the personality of future IT specialists.

Further research is aimed at developing and testing personalized training programs for use in the educational process of universities.

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Computer addiction as a new way of personal self-realization of student youth

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Computer addiction as a new way of personal self-realization of student youth

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Abstract. The article presents the results of an empirical study of computer addiction of student youth in the context of personal self-realization by parameters: motivation to succeed, volitional self-regulation, development of emotional intelligence. The aim of the article is to analyze the manifestations of computer addiction as a new way of personal self-realization, to empirically investigate the relationship of individual psychological factors of self-realization of personality by parameters: motivation to succeed, volitional self-regulation, development of emotional intelligence with subjective assessment of computer addiction by the student youth. Psychodiagnostic methods were used: test for Internet addiction of K. Young; Shostrom's personal orientation (short form) in the modification of E. Jones and R. Crandall; N. Hall's emotional intelligence test, a questionnaire to study the motivation to succeed of T. Ehlers; questionnaire "Study of volitional self-regulation" by A. Zverkov and E. Eidman. The study allowed to obtain significant correlations between computer dependence and the level of self-actualization, volitional self-regulation and its components, self-management of emotions as a component of emotional intelligence. Virtual space for the younger generation in modern conditions serves as a means of meeting those significant needs that are frustrated in real conditions. In particular, personal self-realization in student youth is transferred to cyberspace through new hobbies, acquaintances and attributions of their own "I". Thus, computer addiction in this study was considered as a new way of personal self-realization of student youth, which is still treated mainly as a form of deviant behavior. Self-realization on the Internet for modern youth is a significant area of personal self-realization in general, which under favorable conditions complements self-realization in reality, and under adverse conditions replaces self-realization in reality. Taking into account these points will allow to build a system of psychological work with different levels of computer addiction of student youth in the context of their personal self-realization.

1. Introduction

The Internet is an immanent sign of modernity for people of all ages, regardless of profession, leading social status, age and gender differences. Internet networks significantly affect the development of all social groups, including student youth, while promoting their self-realization and expanding social opportunities. Students not only have the opportunity to use a wide range of information, but also can influence the content of various information resources. Virtual reality is not only a space for comfortable informal communication, but also provides a search for pragmatic information. Modern computer information and communication technologies are becoming part of all spheres of human life, creating new mechanisms of cultural development of mankind, so many authors, among other forms of socialization, consider cybersocialization [1]. Thus, Internet networks have become platforms for learning, implementing business plans and finding employees a long time ago, ie they are a platform for self-realization of educational and professional ambitions of student youth [2, 3]. Internet networks also make it relatively easy for young people to find like- minded people with similar interests and needs; promoting the creation and active development of virtual communities, ie such groups that have common goals and communicate mainly indirectly through information and communication networks.

Virtual reality is part of the psychological reality of human, so self-realization in cyberspace becomes part of our being. According to Yu. Asieieva, adolescents and young people are the most sensitive to the unification and transfer of the reality of life in cyberspace, which is why in the ontogenetic period from 14 to 22 years registered the largest share of people with Internet addiction. The properties of the virtual network (anonymity, accessibility, security, ease of use) allow young people to meet frustrated socio-psychological needs as quickly as possible, to experiment with various transformations of their own identity [3]. Thus, computer addiction in this study will be considered as a new way of personal self-realization of student youth, which is now treated mainly as a form of deviant behavior due to emotional and volitional manifestations of addictive behavior.

For young people, escaping into cyberspace is one of the ways to assert themselves, increase their sociometric status in the group, successful self-realization in virtual reality. The need for self-disclosure in adolescents has the specificity of its manifestation in real and virtual communication, which becomes relevant as a separate topic, and the hierarchy and subordination of these topics [4, 5].

Also, immersion in cyberspace allows to void or forget about unwanted experiences, remotely experience an unpleasant situation for a young person. Therefore, computer addiction is the most common form of personal self-realization in information societies. In general, computer addiction is spreading rapidly among other age groups [6, 7].

Self-realization of student youth through the cyberspace is provided by its positive influences on personal development. The positive factors include: the value orientations of the personality, which are not lost, but determine its self-realization in cyberspace; dialectic of social relations in the virtual reality of the Internet community; protection from situations that create negative feelings in real life; instilling inflated expectations about achievements in professional and social components of life; the ability to ensure presentability and increase the efficiency of communication processes; flexibility of virtual communication in relation to one's own expectations; opportunities to independently design a virtual space according to your own script and implement it in your activities; reduction of restrictions due to specific functions of virtual culture - compensation, balancing or compensation of insufficiently satisfied needs in objective reality; openness, which greatly simplifies mobility processes [5, 8].

The vast majority of student youth creates their own "idealized image" in a virtual environment. This process is dynamic, because in modern mass culture, trends and fashion images that serve as landmarks are constantly changing, mass production makes any sustainable images and actions impossible. In cyberspace, young people have the opportunity to play different social roles and professional-occupational statuses, this is through the creation of new pages with different life stories and "I-images". Such transformations are possible as long as there are no internal contradictions in the structure of self-realization of the individual [9, 10].

The aim of the article is to analyze the manifestations of computer addiction as a new way of personal self-realization, to empirically investigate the relationship of individual

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psychological factors of personal self-realization by parameters: motivation to succeed, volitional self-regulation, development of emotional intelligence with subjective assessment of computer addiction by the student youth.

2. Methods

Based on the principles of a systematic approach, computer addiction as an integral part of self-realization of student youth in cyberspace was considered as a socio-psychological phenomenon that has many psychological correlates; its development is ensured by the interaction of emotional, volitional, intellectual components of young people's mental activity, which will promote dynamic cooperation of young people with diverse interests (educational, scientific, artistic, communicative, etc.) and provide new opportunities for activity and self-realization.

K. Young's test was used to detect computer addiction, which detects the dynamics of Internet use and evaluates the symptoms of addiction.

The following psychodiagnostic techniques were used to study the psychological correlates of computer addiction:

(i) E. Shostrom's personality orientation questionnaire (short form) modified by E. Jones and R. Crandall;

(ii) N. Hall's emotional intelligence test (IQ) to study the components of emotional intelligence on 5 scales: emotional awareness, self-emotion control, self-motivation, empathy and control of emotions of others;

(iii) questionnaire to study the motivation to succeed by T. Ehlers;

(iv) questionnaire "Study of volitional self-regulation" by A. Zverkov and E. Eidman to study self-regulation as a behavior that takes into account the results of self-knowledge, reflection and emotional-value attitude towards themselves.

The empirical study was conducted with the participation of full-time and part-time students majoring in 053 "Psychology" at the Faculty of Linguistics and Social Communications of the National Aviation University. Age category: from 20 to 28 years. The total number of respondents is 66 people (100%). The sample was formed on the principle of random selection (randomization).

Mathematical data processing was performed using the SPSS 17.0 statistical package for Windows.

3. Results

According to the method of K. Young, all 100% of respondents in our sample had a slight degree of Internet addiction. That is, they are able to control their actions, can correct them in time or even cancel. They have a sense of control and predictability of their own actions. At the same time, using the Internet brings them positive emotional arousal (especially online games), which causes a slight degree of dependence.

Diagnosis of the need for self-realization according to the modified questionnaire of personal orientation by E. Shostrom showed that the vast majority of respondents (64%) have a high need for self-realization, the remaining 36% - average. Such results are obvious in view of the socio-economic demands (search for passionate individuals who have the desire and potential to improve the world, are potential agents of change in society, initiators of positive changes) that shape the labor market.

Self-realization is more successful and full-fledged when young people are involved in a sufficient number of social connections, so interpersonal communication is especially important here. On the one hand, communication with other people gives the opportunity to acquire new thoughts, goals and values, and, on the other hand, there is a translation of their own accumulated knowledge, experience, which provides not only follow but also continuation in others. Thus, there is a fusion of two aspects of self-realization: creativity and communication, which are especially important in the case of self-realization of the personality through the Internet.

Therefore, the next method, the results of which it was appropriate to analyze was the test of emotional intelligence by N. Hall. The results of the method are presented in (table 1).

Table 1. The results of the diagnosis of emotional intelligence by the method of N. Hall "Emotional Intelligence Test".

Levels	Emotional awareness	Controlling personal emotions	Self-motivation	Empathy	Controlling emotions of others
High	45 %	18 %	27 %	45 %	27 %
Medium	41 %	27 %	27 %	45 %	55 %
Low	14 %	55 %	46 %	10 %	18 %

As we can see, respondents rated themselves highly on the emotional awareness scale: 45% of the sample well understand their emotional states and the reasons for their manifestation, and 41% of the sample understand the vast majority of their emotional states and their causal links with the events in their own lives.

It may seem that a person who understands, monitors own inner states, distinguishes them, at the same time must be able to manage them, know how these experiences arise and why they are necessary. But the understanding of emotions does not always develop into the ability to manage them: 55% of respondents have a low level of control over their own emotions. This result indicates a weak level of self- regulation of respondents, they reflect well on their states, but can not control them. For example, when we feel fear, we try to calm ourselves down, to suggest that everything is fine and we are not afraid of anything, but models of emotion management due to denial are not effective. It is much more useful to accept and live through it than to fight them, this function is often simulated for us by virtual reality: it allows us to experience emotion, get mental relief, which has a positive effect on psychological and physical condition, allows to continue activities.

Indicators on the scale of self-motivation are consistent with indicators on the scale of emotion management: respondents are mostly limited in their ability to control their activities to achieve the goal. This can give good results, but in the long run this method is not ecological towards oneself, because it can lead to emotional burnout, decreased productivity, psychosomatics, depression, and so on.

Respondents rated their empathy quite highly: 45% at high and medium levels. They are characterized by a peaceful attitude to the world around them, without conflict, because in difficult situations they try to coordinate actions aimed at sincere, calm communication, as they have a hard time experiencing conflicts.

The contradictory result is that despite the low level of management of their own emotions (55% have a low level), the vast majority of them are able to manage the emotions of others. In general, 83% of respondents believe that they know how to control other people's emotions, 27% of them are able to do it at a high level, and 55% at a medium level, ie situationally. Students find that it is easier to influence another person and their psychological state, perhaps because they are looking for such intermediaries, including on the Internet, and for themselves.

Based on the general results obtained by the method of N. Hall, it can be stated that young students are confident in their own awareness of themselves and others, but not motivated enough to achieve their own goals. To confirm this assumption, methods of diagnosing achievement motivation and volitional self-regulation were used. Analysis of the results according to the method of T. Ehlers on the diagnosis of motivation to succeed showed that a significant proportion of respondents 68% have a moderately high level of motivation to succeed, 32% - medium. Developed motivation to succeed in student youth helps to increase the focus on results in current activities and will affect other basic competencies that help solve life problems: initiative, communication, ability to influence others, organization, responsibility, rationality.

The questionnaire of A. Zverkov and E. Eidman allowed to assess the level of development of volitional self-regulation in respondents. The majority of respondents (54%) have a high level of volitional self-regulation, ie they can influence the direction and dynamics of current activities, are well-adapted, active, independent individuals. 23% of respondents have medium and low levels of self-regulation. They are less able to control their actions, the course of activities, do not have a stable socially positive orientation. 68% of respondents showed a high level of persistence. It is known that persistence is considered by many scholars as a predictor of success in various activities, including educational and professional. That is, such students are characterized by a more active, independent position and less likely to pay attention to difficulties. According to the following scale of "self-control" (the ability of the subject to control their emotions, thoughts and actions in difficult uncertain situations) were obtained much lower overall results: high score showed 36% of respondents, medium - 41%, the rest low. These results are partially consistent with the "Emotion Management" scale according to Hall's method. At the same time, self-control is a resource for the psychological well-being of the individual, a means of maintaining mental and physical health, which allows in the course of daily events to maintain the necessary balance in professional activities, personal life and relationships with the world. Thus, the presence of developed emotional and volitional substructures of the personality protects it from various dependencies and even addictions, including computer addiction. Thus, V. Synyshyna and L. Yakovytska noted in their research that the possibility of self-realization of a personality is a constant self- development due to the ability to plan and carry out actions; mobilizing oneself to overcome difficulties; objective assessment of their strengths and weaknesses, the level of their readiness for new, more complex actions and deeds; ability to regulate the motivational-volitional sphere [11].

To determine the statistical significance of the results obtained, we conducted a correlation analysis of data to establish relationships between the following indicators: computer dependence, self-realization, volitional self-regulation and its components, emotional intelligence, motivation to achieve. According to the results of correlation analysis according to Pearson's criterion, a direct positive relationship was established between the degree of Internet addiction according to K. Young and the level of self-realization according to E. Shostrom ($r = 0.416$, at $p \leq 0.05$). This result suggests that the computer addiction of student youth is part of the content of self-realization of modern human, which is revealed in the manifestation of personal potential through various activities. Significant inverse correlations were also obtained between individual psychological factors of personal self-realization and subjective assessment of computer addiction by student youth (table 2).

It has been found that the relationship between computer addiction and volitional self-regulation and self-control is inversely proportional. That is, even the average level of self-regulation as a component of arbitrary management of the individual's behavior and activities reduces the probability of occurrence of dependent forms of behavior. Volitional regulation of personality occurs when maladaptive actions (manifestations of computer addiction) begin to disrupt the course of significant activities, under such conditions, the ability to regulate compensates for "negative" manifestations of addiction (for example, the network steals student

Table 2. Significant correlations between individual psychological factors of self-realization of the personality and the subjective assessment of computer addiction of student youth "computer addiction".

Parameters	General volitional self-regulation	Persistence	Self-control	Emotional control
Correlation coefficient	-,489*	-,422*	-,560**	-,414*
Significance level	,022	,046	,007	,05
Sample	66	66	66	66

* Correlation is significant at the 0.01 level (2-tailed). ** Correlation is significant at the 0.05 level (2-tailed).

productive time).

E. Ilyin and M. Chumakov in the analysis of the concepts of "emotions" and "will" use the term "emotional-volitional sphere of the subject". This concept is used mainly in experimental studies to describe the regulation of activities in difficult conditions. Indirect evidence of this approach is the inversely proportional relationship between computer addiction and the ability to control emotions ($r = -0.414$, at $p \leq 0.05$). It should be noted that the study is not about the process of emotional and volitional regulation in general, but about an arbitrary way of regulating unwanted emotions by student youth.

It can also be stated that there is an indirect correlation between the need for self-realization and computer addiction (table 3).

Table 3. Significant correlations between the level of self-realization and individual-psychological factors of self-realization of the personality.

Parameters	General volitional self-regulation	Persistence	Self-control	Emotional control
Correlation coefficient	,467*	,608**	,431*	,426*
Significance level	,024	,003	,035	,038
Sample	66	66	66	66

* Correlation is significant at the 0.01 level (2-tailed). ** Correlation is significant at the 0.05 level (2-tailed).

The effectiveness of self-realization processes is due to the systematic interaction of motivational, emotional, volitional and other processes. Reliance on emotional and volitional processes allows a young person to conduct activities more effectively, increase its effectiveness, and the degree of emotional and volitional self-regulation, conscious control of personality in cyberspace, provides new opportunities for self-realization in a comfortable environment.

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4. Discussion

In essence, the Internet is a creative laboratory where a person can search for their own identity, experiment with it, try different ways of self-realization. Internet self-realization can be a kind of springboard for implementation in regular reality. Internet text, a web image or a work of computer art are creative acts. The result is either a specific object or an image of the subject, because man himself acts as an image that can not exist in the virtual world without the appropriate reaction of the Other. V. Goncharov believes that a new form of self-realization can be considered a virtual self-presentation on the Internet. Created by a real person, the virtual is a product of creativity, a new form of self-reflection. As a rule, the virtual personality does not oppose the real one, but complements it, it is a new form of constructing the "I". The author of the article agrees with V. Goncharov that "thanks to the Internet, the creation of a personal "I project" includes its virtual incarnation, through which a person is also connected to the world, as well as through the usual social interaction. Virtual personality allows a real person to feel a new form of involvement in the world" [12]. The use of electronic devices, according to Yu. Asieieva, actualizes the processes of self- realization of the personality in virtual reality. Adolescents and youths are the most sensitive to the creation of the desired and the transfer of the reality of being in cyberspace [3]. In our opinion, internet self-realization can be regarded as compensatory (in the case of problems with self-realization in fact), and as a trial, experimental, but full-fledged in quality, although certainly narrower than self-realization in actual activities.

The main reason for addictive self-realization on the Internet, many believe the difficulties in self-realization in fact and the removal of these problems online. T. Golovanova and E. Vlasova (2019) proved the existence of a link between excessive enthusiasm of young people for cyberspace and reduced self- actualization [13].

Many studies have focused on the impact of Internet use on student self-efficacy. Self-efficacy in these works is defined as people's belief in their ability to control their own actions and current situations that affect their lives [14–17]. We believe that the use of the concepts of "emotional-volitional sphere of personality", "volitional self-regulation" is more appropriate in terms of their clear definition, criterion and instrumental development. Thus, one of the important tasks of educational institutions with students youths is to create favorable conditions for healthy personality development, adequate value and emotional experiences that promote mental balance; formation of the ability to resolve contradictory situations, to adequately assess oneself; learning coping strategies of behavior that increase stress resistance; adaptive techniques of emotional self-regulation and self-realization, as well as correction of already formed addictive patterns.

Summarizing the views of scientists, it can be stated that the model of the desired activity of the personality in cyberspace is not only the process of communication, but also the need or attempt to address the need for self-realization. The most notable phenomena of the antinomy of cyber activity and personality include the emergence of a certain autonomy in various spheres of spiritual and practical life activity in cyberspace. Therefore, the concepts of personality, its self-realization and values, in particular moral and salutogenic, should be closely connected with the obvious value attitude to technologies that significantly improve the quality of daily life.

5. Conclusions

The Internet is an element of objective reality for the modern student, which is an information field - an endless resource of knowledge needed to implement own ideas. Even as an intangible phenomenon, the Internet objectively affects student youth. This influence penetrates not only into the sphere of education, but also into the professional sphere, influencing the course of self-realization and the final results of current activities of student youth.

It is proved that the computer addiction of student youth is part of the content of self-realization of modern human, which reveals personality potential through various activities and can be considered as a new way of personal self-realization. An indirect connection has been established between the need for self-realization and computer dependence through correlation with general volitional self-regulation, self-control, emotion management; a direct positive relationship between the degree of Internet dependence according to K. Young and the level of self-realization according to E. Shostrom ($r = 0.416$, at $p \leq 0.05$); inversely proportional relationship between Internet addiction and the ability to control emotions according to N. Hall ($r = -0.414$, at $p \leq 0.05$), general volitional self-regulation according to A. Zverkov and E. Eidman ($r = -0.489$, at $p \leq 0.022$).

Not all students use the Internet only for educational purposes, their Internet- dependent behavior is due to a number of individual psychological factors, which include: social loneliness, which is formed as a result of underdeveloped emotional intelligence, unwillingness to see and take into account the emotions of others, low self-control and insufficient volitional self-regulation. However, under the condition of integration into the activities in cyberspace of achievement motivation, interpersonal communication, self-realization, there is a comprehensive development of the young person's personality. According to the results of the study, the development of excessive computer addiction is hindered by high self-control and involvement of student youth in various types of social activities: educational, professional, social, scientific and creative.

Promising in the further development of this issue is the study of the influence of social and psychological factors that hypothetically may significantly affect the dynamics and content of Internet-dependent behavior of student youth.

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Incorporation of upcycling techniques into technology education

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Abstract. By surveying 95 students studying design and technology in the light industry, the problems in mastering upcycling technologies were explored, and ways to overcome them were outlined. The analysis of existing problems is carried out at three levels - personal perception of upcycling, the formation of relevant skills and knowledge and lack of experience in scaling personal expertise to a business startups level. All respondents are roughly divided into those who practice upcycling frequently and those who do it occasionally. Another 15% of respondents did not decide on their preferences. Respondent attitude, control of behaviour, and behavioural intentions are the most influential factors that encourage upcycling. The influence of social factors, perceived habits and the presence of facilitating conditions is more moderate. Interviewed students have a poor understanding of the benefits of upcycling. Competence for creativity, which is key to mastering upcycling techniques, is absent in educational and professional programs in technology and design. Several examples of possible changes in curricula from 4 disciplines aimed at the formation of creativity are given. The main reasons that complicate the scaling of acquired skills and knowledge in developing business startups with upcycling are analysed. An example of a designed startup is given.

1. Introduction

New economic ideas and models, which implement the principles of the circular economy and aims to achieve conditions for sustainable development, are gradually conquering the world [1]. In implementing the concept of sustainable development, the economic system can recover, and its impact applies to virtually all sectors of economic activity. Fundamental transformations are taking place and are yet to take place in terms of the effects of economic activity on the environment. These are the development of renewable energy [2, 3]; energy-saving [4, 5]; improvement of water supply and water treatment [6, 7]; spread of green chemistry technologies [8, 9]; widespread use of natural medicines [10, 11] or the development of new drugs from natural raw materials [12].

One of the critical problems is optimal disposal and, if possible, reuse of waste [1, 3]. The global fashion industry annually produces 4% of the world's waste, a whopping 92 million tons [13]. In the UK and the US, consumers annually accumulate about 28 kg and 30 kg of textile waste, respectively [14]. Clothing is a very symbolic product, often a sign of high social status [15]. Consumers want to buy clothes as often as possible. Mass clothing trends provide low quality and inexpensive clothing. Therefore, consumers can buy more clothes and throw away old clothes more often, not because they are worn out, but because they are outdated. Seasonal trends in fashion mean that clothes age very quickly. This pace encourages the replacement and disposal of obsolete but high-quality clothing. Most mass fashion clothing is inorganic or synthetic. Such substances are not able to decompose appropriately in the environment and eventually pollute the water. In the United Kingdom, one of the world leaders in waste recycling, only 30-40% of textiles or clothing is recycled, while the rest remains in the environment. In addition to direct pollution from textile waste, carbon emissions have a significant impact [16,17].

Knowledge of sustainable development principles is concentrated in large industries and disseminated to small and medium enterprises [1]. It must be included in academic and professional training. Universities concentrate the intellectual forces of nations through scholars' knowledge and expertise [18]. Accordingly, the role of higher education in promoting the ideas of the circular economy and the formation of ethical standards for the reuse of products is difficult to overestimate. This role will consist both in the introduction of new organisational forms that enhance the effectiveness of educational activities [19], and in bringing the content of educational programs to the requirements of professional activity in terms of sustainable development [20–22]. A broad bottom-up movement in the transition to circular models will occur only if small and medium-sized enterprises hire graduates with the economic and technical knowledge to change business models.

In Ukraine, some progress has been made in implementing sustainable development in technological and professional education, and however, implementation is still inconsistent and fragmented. After analysing the training programs in Professional Education in various specialisations and specialities, it was found that the competencies of graduates required for sustainable production are not provided at the level of approved standards of higher education in Ukraine. As a result, students have specific gaps in knowledge.

The competencies that future specialists should master are listed in the relevant standards of higher education in Ukraine. Students enrolled in training programs for technology education specialising in textile technology have to:

a) be able to implement effective methods of work organisation following the requirements of environmental safety;

b) be able to design and manufacture modern clothing for various purposes;

c) be able to organise the educational process in the disciplines of sewing in vocational education colleges;

d) know the methods of optimising materials usage and reducing waste during the manufacture of new products.

All the listed knowledge and skills belong to the requirements of a linear economy, while there are no skills that need a circular economy model. A whole layer of knowledge about existing and promising approaches and technologies is ignored. The ignored technologies are aimed at waste administration, both at all stages of production and the stage of use and subsequent disposal of used products. First of all, we should mention the technologies of recycling and upcycling. At the same time, there is a steady demand from stakeholders for professionals with these technologies. It is necessary to introduce such skills into the educational process of technology education in Ukrainian universities to train specialists capable of working in a stable environment according to modern circular economy models.

The article aims to formulate existing problems and explore ways to form the necessary competencies of future technologists and designers of the light industry, which will provide knowledge and skills on waste disposal of fashion industry products and work in the business environment of circular economy models.

2. Materials and methods

2.1. Sample of respondents

The research was conducted at the Faculty of Fashion Industry of Kyiv National University of Technologies and Design (KNUTD) with students of different years of enrolment from 2014 to 2017. Students studied in two educational programs aimed at training engineering and pedagogical specialists for the light industry. The number of students in the groups varied from 15 to 25 people. A total of 95 people took part in the survey. One part of the students minored in textile technology, and the other - in textile design.

Opportunities for the introduction of skills in working with waste textile production and used textile products were assessed in the process of teaching two disciplines, "Creative learning technologies" and "Fundamentals of engineering and pedagogical creativity."

With a volume of 180 h (6 ECTS credits), the first discipline included 54 h of lectures and 76 h of practical work. The second had a volume of 270 h (9 credits), including 44 h of lectures and 66 h of practical classes. The problem situation development method (PBL) and the project-based method (PjBL) were actively used. These methods are described in many works [23–26]. Their application in the context of the study is described in more detail in [27, 28]. The programs of both disciplines were supplemented with new lectures and practical classes to master the main components of PBL and PjBL methods. Mandatory development of an independent project was included in the discipline's curriculum as an individual research task. Students began developing real projects in the eighth semester and completed them over eight weeks.

Students participated in a survey to determine personal motives for participating in activities related to processing raw materials. The survey was conducted according to the principles of the combined model of Theory of Interpersonal Behaviour (TIB) [29] and Theory of Planned Behaviour (TPB) [30]. The main principles of the combined model and the questionnaire used are described in [31–33]. A 7-point Likert scale was used for the answers [34]. A 7-point Likert scale ranges from one extreme to another, like "extremely likely" to "not at all likely." As an example, we can say that such a scale includes options: strongly disagree; disagree; somewhat disagree; either agree or disagree; somewhat agree, agree, agree entirely.

The advantages of the 7-point scale are that: it is the most accurate scale among other Likert scales; it is easy to use; it better reflects the true assessment of the respondent. At the same time, as a disadvantage, it is known that previous questions may influence the respondents' answers. When analysing the results, mode (the number of times something happens) indicated the most common response to each statement, and the average - the overall average answer.

The responses were analysed by employing descriptive statistics, correlation analysis and non-parametric statistics for comparing groups. Statistical Package IBM SPSS ver.21 was used.

2.2. Theoretical background

The fashion industry promotes mass and fast consumption. People buy clothes to wear for a short period. Then these clothes quickly turn into textile waste. At each stage of the life cycle of a textile product, a massive amount of waste is generated. The waste consists of end-of-life material that is usually disposed of with other trash, polluting the environment. Textile waste can be classified into three categories [13].

(i) Residues of any manufacturing process in the textile and garment industry, such as pieces of fabric, yarn, leather, etc. Such waste can be called textile waste before consumption.

(ii) The second type is called textile waste after consumption. These are clothes that have lost their attractiveness or their functional properties or have collapsed. Clothes waste is often shipped and sold second-hand in developing countries.

(iii) The third category is post-industrial textile waste (gases, liquids,solids, etc.) formed during production processes as by-products.

Waste before consumption is more accessible to recycle than waste after consumption [15]. Production waste can be collected at the factory and reused together with primary materials for yarn production. This practice is more common than the use of post-consumer waste. But the problem is that the amount of waste after consumption is excessive and constantly increasing. This problem is unlikely to be solved entirely as long as designers in developing their products will not "embed" the possibility of their reuse, style change, design change, and build the option of re-production in the design of all products.

Business models of the circular economy can be divided into those that contribute to the reuse and extension of service life through repair, restoration or modernisation. And also on those that turn old goods into new ones by various types of material processing or recycling [1]. Many definitions characterise the types of recycling of materials and things [31, 35]. In the context of this work, we will use the following definitions.

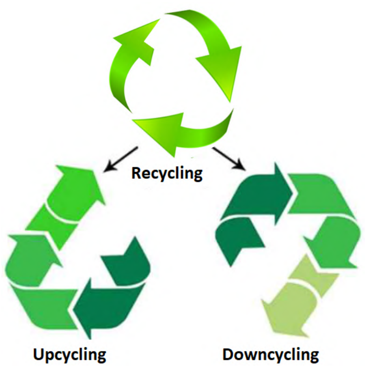

Figure 1. Diagram illustrating different types of recycling.

Recycling is a method of reusing or recycling used clothing, fibrous materials, and waste materials in the production process. As illustrated in figure 1, recycling can go one of two ways, as they differ in results obtained. The first way is downcycling when receiving the substance of lower quality due to recycling. Such a substance can be processed into a more inferior quality product. As a rule, the decrease in quality is due to the nature of the material, which does not allow it to retain its original shape and primary properties during processing. For example, the plastic obtained from the processing of plastic bottles is weaker, and secondary metals have more harmful impurities than similar primary metals. In this way, used clothes can be processed into non-woven textiles, building insulation, rags or carpeting.

Otherwise, it is possible to use the object without compromising the quality of the material from which it is made. This path, called upcycling, can be illustrated as upward processing as opposed to downcycling, where downward processing takes place. Upcycling should be considered primarily as a process of reconstruction. In other words, it creates an original waste product that usually has a higher retail cost than traditional recyclables. You can use different raw materials for upcycling - both waste before and after consumption or a combination thereof.

The process of downcycling, in most cases, can be imagined primarily as a technological process. Conversely, the upcycling process is hardly possible without a vital design component. Accordingly, the role of designers and technologists of textile products is crucial for upcycling textile materials and products. For this reason, in the future, this work will focus on the problems of upcycling in the first place.

Although upcycling is not always separated from other types of recycling, a significant difference is the additional energy consumption. Upcycling does not require processing and therefore does not require extra energy. It can be positioned between reusing and recycling. Thus, waste upcycling is one of the most sustainable circular solutions among waste disposal strategies.

3. Results and discussion

Creating business models in the fashion industry based on circular economy principles has at least three different dimensions. The first is related to personal characteristics and psychological motivation for the use of upcycling technologies. The second dimension is the availability and development of individual skills, knowledge and skills in upcycling. The third level is the knowledge and skills needed to apply upcycling technologies in the business environment.

The following three sections of this chapter will be devoted to analysing the availability and ways of developing competencies for each of the three listed dimensions of the problem of mastering upcycling technologies.

3.1. Psychological motivation

The deepest level that shapes a person's attitude to upcycling, as already mentioned, is the level associated with a person's characteristics. This dimension has been studied in detail in the works of K. Sung [31,32,34–37], which in turn took as a basis the known theories of interpersonal behaviour [29, 30, 38, 39]. Unlike other models of interpersonal behaviour, the Triandis' TIB model is known for its broad applicability [33]. In addition, this model is inclusive and therefore is the complete socio-psychological theory of behaviour and change.

The TIB model was modernised considering other theoretical ideas in [31, 32, 34]. The scheme illustrating the updated model of TIB [29] using the elements of TPB [30] is shown in figure 2. According to this scheme, TIB identifies three main factors that shape the probability of behaviour on the one side. They are the behaviour intention, the strength of habits, and the presence or absence of hindering or facilitating conditions. Habits are measured by the number of attempts to act [29]. Facilitating conditions are, for example, tools, products, materials or other favourable things or their absence. An indicator frequency of upcycling, how often the person resorted to the practice of upcycling, characterises behaviour for the other side.

In turn, behaviour intentions are formed under attitude, social factors, and perceived behaviour control. Attitude is formed by perceived consequences and the value of the consequences. Perceived consequences refer to the subjective probability that inevitable consequences will follow certain behaviours. The value of the consequences characterises the degree to which a person responds to the actual consequences, both good and bad [29]. If the expected and already experienced consequences are positive, they play the perceived benefit role. This case is illustrated in figure 2. The emotions also influence attitudes that a person feels when thinking about their behaviour. They can also be either positive or negative.

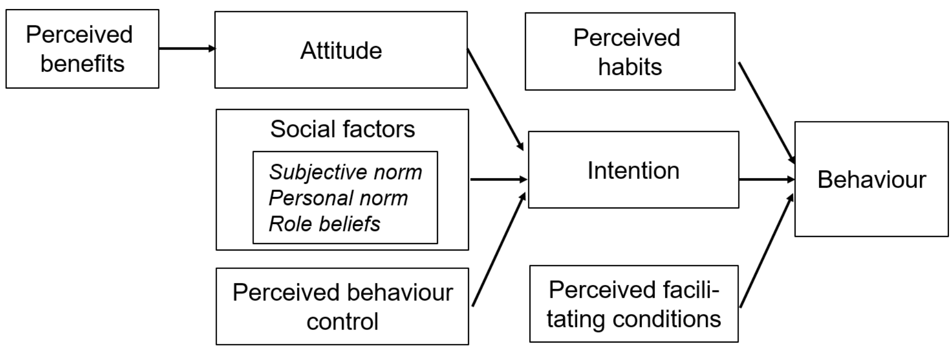

Figure 2. Combination model of Theory of Interpersonal Behaviour and Theory of Planned Behaviour after [31, 32, 34].

The TIB model illustrates social factors with three elements: subjective norms, personal norms, and role beliefs (figure 2). Subjective norms are the belief that a particular behaviour is correct, appropriate, or desirable. Roles are sets of behaviours considered acceptable to those who hold certain positions (e.g., parents, leaders, etc.) in the group. Personal norms are a person's idea has about oneself. In other words, it is a self- concept.

Behaviour intentions are also formed under the influence of perceived behaviour control, as it follows from the model [30] and is taken into account in the modernised scheme in figure 2. This factor refers to the control over the implementation of certain behaviours.

Obviously, concerning waste recycling, the factors influencing behaviour will include the benefits that recyclers receive, the social factors they consider relevant, the emotions associated with recycling, the experience of previous activities. The benefits can be economical (cost savings), environmental (waste reduction), psychological (well-being) and socio-cultural (recognition and evaluation by others). It is also essential to have favourable conditions, such as access to tools or lack of appropriate means. Social factors included social norms such as ecological awareness, roles such as being "helping and correcting", and self-identification as an ecologist.

A survey of future technologists and designers of the light industry was performed to determine the probable behaviour in upcycling matters and the main factors that shape this behaviour. The questionnaire was developed for use within the scheme in figure 2 in [32]. The questionnaire questions are grouped into ten blocks according to figure 2. The answers allow us to assess the attitude of respondents to the following factors:

- Perceived benefits;
- Attitude;
- Subjective norm - social factor 1;
- Personal norm - social factor 2;
- Role beliefs - social factor 3;
- Perceived behaviour control;
- Intention;
- Perceived facilitating conditions;
- Perceived habits;
- Frequency of upcycling as a measure of expected behaviour.

Respondents' attitudes towards upcycling, i.e. their expected behaviour, were determined using the indicator of respondents' frequency of upcycling practices. The results in the number of observations as a function of the frequency of upcycling are shown in figure 3. Shapiro-Wilk tests of upcycling frequency allow us to state the presence of a normal distribution of results with a probability of $p_{SW} < 0.00152$.

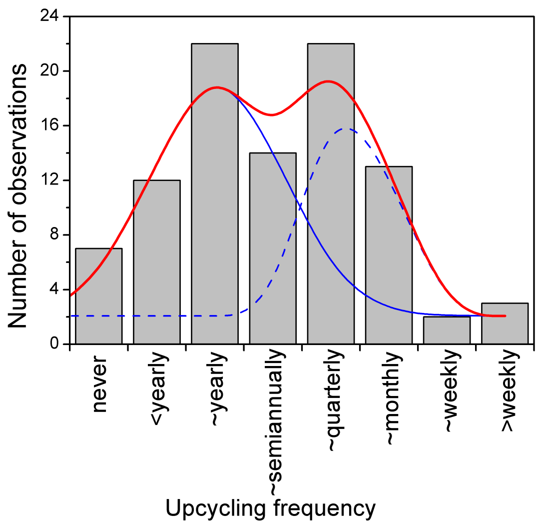

Figure 3. Distribution of the number of observations on the frequency of application of upcycling.

The bimodal nature of the distribution curve in figure 3 is evident. In other words, the sample of respondents contains two branches that partially overlap. The branch that accumulates respondents with less upcycling practice, which can be conditionally called a group of negative attitudes (n-group), is more numerous. It includes 41 respondents who, on average, practice upcycling about once a year (spread from never to once every six months). The group following active upcycling includes 40 people with an upcycling frequency of once every 1-3 months or less (positive attitude group or p-group). The remaining 14 people in their answers indicate the frequency of upcycling is about six months (0-group). So it is difficult to attribute them to supporters or opponents of upcycling. Accordingly, such respondents are grouped into a group with an as yet unformed attitude to upcycling.

The study allowed us to assess the significance of the influence of various factors on the expected behaviour. For six of the seven influencing blocks (figure 2), conclusions are made based on analysing answers to several (from 3 to 15) homogeneous or complementary questions. It gives grounds to calculate the average response rates for each block and then operate with the averages for each of the three identified groups of respondents.

The questionnaire used 15 disparate questions to assess the impact of the remaining seventh factor, namely the perceived benefits. They cannot be combined and therefore cannot be operated by averages. In this case, the analysis was performed for 15 individual questions. The most influential questions are revealed, and the characteristic answers to them are specified. We consider influential those questions, the typical responses to which exceeded the border 4 points and tended to 5-7 points.

The average survey results for the three groups (p, n and 0) are shown in figure 4a. The most influential factors were attitude, perceived behaviour control and intentions. Attitude and control factors, according to figure 2, directly affect the formation of the respondents' intentions. Their estimates of the strength of influence vary between somewhat agree and strongly agree. The greatest strength of agreement is demonstrated by group p, followed by group 0. The power of the consent of group n is always lower. In the case of assessing the factor of intent, it almost disappears to zero. It is not surprising, as this group brings together respondents with the most sceptical about upcycling.

The strength of the influence of the other three factors is much lower. Estimates of social and habitual factors are a little short of the "somewhat agree" assessment. There is no agreement for group n. The situation is reversed for the facilitating condition factor. The importance of the presence of facilitating conditions is indicated by the respondents of groups 0 and n. At the same time, the facilitating conditions are not crucial for the respondents of the group p.

The values of the expected benefits of upcycling came as a surprise. Any of the 15 benefit options did not receive at least minimal support among the group of students as a whole (figure 4b). The answers to the questions about the availability of benefits ranged from "neither agree nor disagree" to "somewhat disagree". The division of students into three traditional groups also did not reveal a significant difference between the groups and perceived benefits of upcycling.

More clear results can be obtained by identifying a group of strong recyclers, i.e. respondents who practice upcycling weekly or even more often. However, only five people can be included in this group (i.e. about 5%) out of 95 surveyed students. In other words, the vast majority of students are not aware of the possible benefits of using upcycling. At the same time, according to figure 2, perceived benefits form the value of the attitude to upcycling. If there is a positive attitude (figure 4a), most students' lack of perceived benefits looks rather strange (figure 4b).

According to the scheme in figure 2 and the obtained survey data (figure 4), the attitude and control of behaviour to a greater extent form the intentions, which in turn implies the probability of behaviour. According to the results, the role of other factors, namely social and facilitating conditions and acquired habits, is slightly smaller. Social factors and acquired habits still play a role for groups n and 0 but are almost invisible in group p. The lack of facilitating conditions is essential for groups with unformed (group 0) or restrained (group n) attitudes to upcycling but is not critical for persistent supporters (group p).

There are probably two reasons that may explain the discrepancy between the high level of attitude and the low assessment of perceived benefits. First, it is insufficient attention, unformed infrastructure and legislation on waste recycling in Ukrainian society. Accordingly, people who, for personal reasons, do not practice upcycling often and regularly do not feel the public need and are not aware of the potential benefits of such activities. Those who resort to upcycling often and regularly have realised the benefits with the help of their own experience.

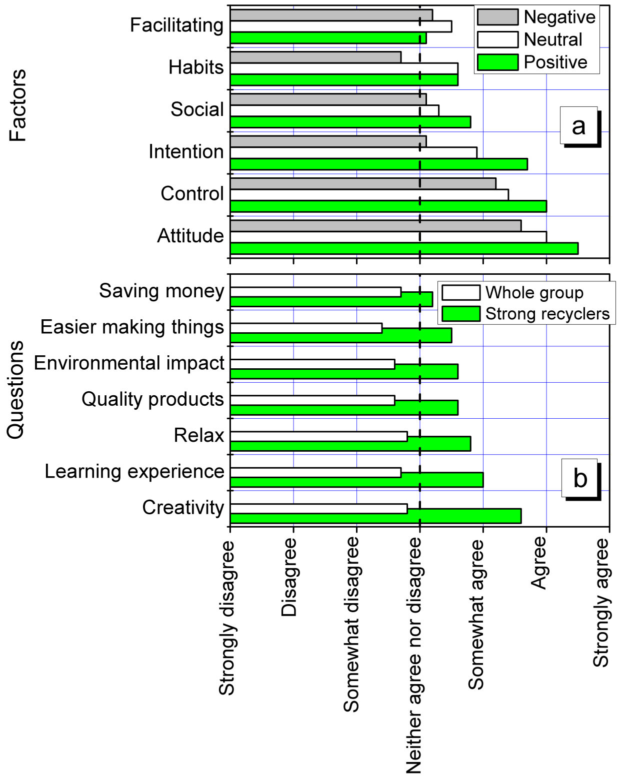

Figure 4. Degree of agreement or disagreement of respondents with the impact assessment of: a - some factors on the propensity to upcycling, b - some questions about the expected benefits.

The second reason concerns students who, by their speciality, are related to industries that produce a lot of waste. As mentioned earlier, the fashion industry belongs to such sectors. For such people, a lack of understanding of the potential benefits of upcycling indicates an education gap. In other words, the list of competencies that future technologists and designers must master does not involve the development of knowledge and skills needed to understand the importance and mastery of upcycling techniques.

3.2. Necessary changes of educational programs

Upcycling can exist on different scales, i.e. at the industrial, small business or individual level. At the personal level, upcycling is mainly becoming a way of life. It is becoming part of a variety of movements aimed at reducing waste and achieving sustainable consumption. As a result, the number of people who share information and physical resources, both online and offline, is increasing.

There are like-minded people with similar values that promote the exchange of resources, skills and knowledge on waste reuse and product development and manufacturing. Such communities form new organisational forms. Examples are training in upcycling for ordinary citizens [33], master classes for students [40], the creation of upcycling stations [41]. The upcycling station combines the functions of hazardous and bulky waste disposal, an exchange platform that allows citizens to exchange items in good conditions. In addition, such stations are permanent workshops where processing and repair work is carried out.

Due to the specifics of clothing products, upcycling in design and production is mainly applied to unique products or for minimal series by tailors or small companies. However, in organisations and communities that professionally discuss the problems of upcycling, the focus is gradually shifting from individual upcycling to the development of forms of small or medium scale [33]. New opportunities open up if we apply upcycling in the mass production of companies interested in a more environmentally sustainable solution to their problems with textile waste.

The results of several studies [42–44] indicate that there are significant differences between traditional fashion clothing and recycled clothing. These differences are formed at the stages of design and production. For effective advanced fashion design, fabric supply must occur much earlier than in standard design and production. Pattern cutting methods should take into account the variability of the fabrics supplied. Information on the availability of raw materials should be available from the outset to achieve design consistency throughout production. In addition, it is necessary to take into account the features of the national waste disposal system, which may change over time and countries [45, 46].

Establishing sustainable production can provide several competitive advantages if you integrate the value created into a single vertical chain by strengthening creativity, improving clothing design and participating in marketing and sales. The strategy of integrating design and retail can lead to a more flexible design process and, consequently, to increased productivity.

It becomes apparent the need to create different design processes and methods for recycling and reuse of waste [33]. The integration of waste and recycling into the design process requires a change of thinking and approach. The design process depends on the type of waste collected and therefore requires constant adaptation and experimentation. In addition, the reuse of waste faces problems related to the search, transportation, treatment and storage of waste before use in the production process.

Thus, more experiments, wider use of the method of "trial and error" are fundamental conditions for the creative recycling process. For young technologists and designers to be ready for these new challenges, some changes need to be made in their training programs. This specific problem is part of a more general problem of forming the necessary competencies for students to work in the era of sustainable development [47, 48].

At this stage of development of Ukrainian education, the competence "ability to generate new ideas (creativity)" is absent in the current, approved from 2018 to 2020 state standards of higher education for bachelors and masters majoring in 022 Design, 182 Technology of Light Industry Products, and 015 Professional Education (for similar specialisations). This competence is absent in the list of general, special, professional and subject competencies. This situation means that educational components may not support the formation of creativity.

Although in the preparation and discussion of new Ukrainian standards, attention was paid to the importance of such competence [49, 50]. In particular, in the list of competencies according to employers and graduates, "the ability to generate ideas (creativity)" is referred to as general system competencies [49]. All stakeholders call it one of the most important and necessary, along with "developing an entrepreneurial spirit", "the ability to act in unusual situations", and "concern for quality".

Table 1 shows examples of the author's experience of implementing new methods and tasks to form creativity and organising sustainable production using upcycling techniques in students majoring in 015 Professional Education (minoring in Design and Technology of Light Industry Products) at KNUTD.

In the vast majority of cases, students learn upcycling at home or work. As an example, we can cite a design studio that practices waste-free production. From the remnants of fabric, employees make various items of home decor in the style of patchwork. Small remnants of materials are not thrown away but transferred to children in schools. There they are engaged in creativity in lessons of labour training or needlework circles.

The formation of the competence of graduates to work in the era of sustainable development can occur during the study of various disciplines. The analysis of foreign experience allowed one to specify the number of possibilities of introducing upcycling in the educational process. Among them are holding separate one-day workshops; development of student projects using upcycling within the study of some academic courses, such as sustainable design or apparel design [17, 33, 40–42].

Reducing waste and creating new products does not require high additional costs. However, one needs to consider the following:

1. Companies that will use upcycling technologies should worry about upgrading and using the appropriate software.
2. They should encourage the creative activity of their designers.
3. They need to enter the market and promote their products through a marketing policy that attracts environmentally sensitive customers.
4. As part of this strategy, designers need to develop a "clothing roadmap" that will offer environmentally friendly clothing and textile waste solutions.

Table 1. Examples of components of educational programs of the speciality 015 Professional education (minoring in Design and Technology of Light Industry Products) at KNUTD.

Type of activity	Description of students' activity	Purpose
Discipline:	Methods of professional training	
Practical lesson: "Setting didactic goals of professional training"	Students formulate didactic goals of vocational training on the topic, while they need to take into account the level of students' mastery of educational material	Learn not to limit the goals to the third level of knowledge; plan tasks so that students try to make non-standard solutions
Discipline:	Fundamentals of engineering and	pedagogical creativity
Practical lesson: "Methods of solution of creative problems: SCAMPER"	Students choose a garment and make sketches of possible uses for another purpose	Development of creative thinking to predict possible transformations and new applications of products
Homework: "Sewing Upcycling"	Students choose a used garment or knitwear and change it to meet current fashion trends	Get experience in upcycling a garment or knitwear
Individual task: Development of a project to organise upcycling light industry products in the community	Students study the complete cycle of individual project development incl. purpose, tasks, plan, terms of realisation, budget, result publishing	To form skills and abilities to develop projects aimed at upcycling light industry products in different types of communities
Discipline:	Fundamentals of clothing design	
Individual task: Development of a fashionable image for participation in the Chestnut Constellation competition	Students develop a fashionable image following the requirements of the Chestnut Constellation competition. Participate in the one image contest	To form abilities and skills of development of a fashionable image, using techniques of upcycling
Discipline:	Creative learning technologies	
Practical work: Development and implementation of webinars	Students develop a script and independently conduct a training webinar - a master class on using one upcycling technique	Develop skills and abilities to arrange webinars to teach a range of upcycling techniques

3.3. Example of a start-up project

The content of previous considerations concerns an individual - from the motives of his behaviour to the acquired skills and abilities. Accordingly, the acquired knowledge is essential for understanding human behaviour, for example, in the development of its social activity, participation in social movements and activities in social networks [33].

However, the acquisition of personal skills is one thing, and another is the acquisition of skills in real life and the implementation of these skills in business projects. Upcycling is essentially a social movement that can be converted into a means of achieving sustainable development. However, it needs support from below at the level of individuals and above at the government and business levels. It is necessary to create a prototype of the proposed interventions that would help scale up the movement for textile waste processing at the next stage. In this case, upcycling, in addition to the popular social activity, will increasingly acquire the features inherent in business models. The main advantage of such constructions is the possibility of embedding upcycling technologies in business models capable of working in a circular economy (figure 5).

Under the conditions of higher education institutions, continuing education is carried out during the students' independent research. Student research allows one to acquire the knowledge and experience needed to scale upcycling from a social activity to independent business projects.

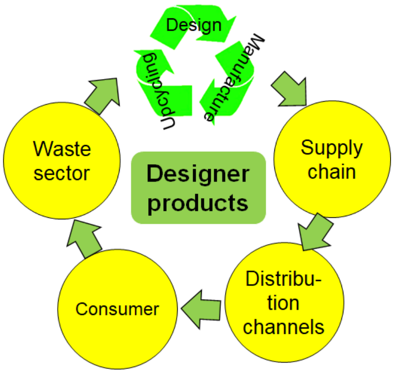

Figure 5. Circulating business model using upcycling of textile waste.

Opportunities for the development of student research are illustrated by the example of the start-up project "Designer Products from Textile Waste: Creation and Sale". The initial goal was to assess the possibility of creating a company that focuses on the processing of used clothing and textiles to develop new products. To achieve this goal, the essence of textile waste and critical problems in this area were identified.

The Lean Canvas business plan template created by Ash Maurya was used to develop the project's business model. The template helps to state the main idea in its fundamental assumptions, using nine basic blocks [51].

This template was adapted from Alex Osterwalder's Business Model Canvas [52]. It was optimised for the Lean Startup methodology with a strong emphasis on finding customer issues that need to be addressed.One of the main advantages of Lean Canvas templates is their excellent flexibility allowing quick changes and updates of business project parameters. Blocks 2, 4, 7 and 8 characterise the product under development (figure 6). The expected market conditions are described in blocks 1,3, 6 and 9. Block 5, one of the key ones in the scheme, is relevant to both the product and the market environment.

Product			Market	
2. Problem 97% of textile waste goes to landfills and remains a source of pollution. There are thousands of vulnerable people in Ukraine: women with disabilities and unemployed young single mothers	***4. Solution*** The organisation of sewing workshops where unemployed and other vulnerable people will work and create new products by recycling textile offcuts	***5. Unique value proposition*** Reducing the amount of textile waste that goes to landfills. Providing work for people in need of special social protection	***9. Unfair advantage*** Special technologies, affordable prices, the client database	***1. Customer segment*** Clients aged 35 - 60 years, primarily female gender who concerned about the environment and ethical products
	7. Key metrics Sales revenue, net profit, employee happiness, customer acquisition cost, monthly website traffic		***6. Channels*** Social networks, online store, retailer network	
8. Cost structure Purchase of equipment, rental of premises, marketing channels, staff salaries, costs for carriers and textile waste suppliers			***3. Revenue streams*** Revenue from sales of products, repair and reuse service, participating in new projects, government subsidies and private grants	

Figure 6. The Lean Canvas business model plotted using the template from [51]. It illustrates the implementation of the project "Designer Products from Textile Waste: Creation and Sale".

According to the business plan, a line of products for different target segments of customers is planned for production by recycling textile waste and used textiles. The product line includes:

1. Designer clothes: dresses, skirts, blouses, bathrobes, uniforms.
2. Designer accessories: bags of different sizes, organisers for bags, aprons, garden and oven gloves, scarves, shawls, smartphone cases, etc.

A temporary or preliminary solution is opening a garment workshop to upcycle clothes and textile waste to create new products. The first stage of the project - to start sewing products from textile cuts; promote these goods on the market (social events, fashion shows); study sewing technologies from textile scraps; sell textile scrap products through online channels.

The long-term solution is to create a company that can provide a full-cycle process from collecting and upcycling textile waste to creating designer environmentally friendly recyclable products at reasonable prices, design and quality. The undeniable advantage of such products will consist in reducing the amount of textile waste. In addition, people who need special social protection will be able to get a job.

The development and subsequent implementation of similar projects will play an essential role in gaining professional experience by future technologists and designers of the textile industry in the functioning of circular economy models.

4. Conclusions

1. Through a survey according to the combined model of Theory of Interpersonal Behaviour and Theory of Planned Behaviour, the personal motives of students of technology and designers regarding their participation in activities related to the processing of raw materials are determined. According to the frequency of application of upcycling techniques, all respondents have divided approximately in half. The division is between those who practise them regularly (once per 1-3 months or more often) and those who use them infrequently (once a year or less). About 15% of respondents did not decide on their preferences.
2. Regarding the prospects of introducing upcycling technologies in future professional activities, there are problems at three levels - personal perception of upcycling, the formation of relevant skills and knowledge and lack of experience in scaling personal expertise to the level of business startups.
3. Factors influencing the commitment to the use of upcycling are identified. The most influential is one's attitude, control of behaviour and formed intentions. These factors shape the behaviour of all defined groups, regardless of the frequency of application of upcycling techniques. The influence of social factors, perceived habits and facilitating conditions is more moderate. It affects the behaviour of people who are more prone to upcycling and has almost no effect on indifferent people.
4. The contradiction between the high level of attitude and low evaluation of students' perceived benefits is revealed. Most students have a poor understanding of the benefits of upcycling. People who, for personal reasons, do not practice upcycling often and regularly do not feel the public need and are not aware of the potential benefits of such activities. An important reason for this attitude is the education gap.
5. A lack of attention to the development of competence "creativity" presents in the current higher education standards in the relevant fields of knowledge. Meanwhile, generating ideas is key to mastering upcycling technology by textile industry specialists.
6. Examples of possible changes in the curricula of disciplines "Methods of professional training", "Fundamentals of engineering and pedagogical creativity", "Fundamentals of clothing design", "Creative learning technologies", aimed at the formation of creativity, have already passed practical testing at KNUTD.
7. The main reasons that complicate the scaling of acquired skills and knowledge in developing business startups with upcycling are analysed. An example of the developed startup project "Designer Products from Textile Waste: Creation and Sale" is given.

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