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Advancing Education in Challenging Times: A Review of the XVI International Conference on Mathematics, Science and Technology Education (ICon-MaSTEd 2024)

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Advancing Education in Challenging Times: A Review of the XVI International Conference on Mathematics, Science and Technology Education (ICon-MaSTEd 2024)

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Abstract. This paper presents a comprehensive review of the XVI International Conference on Mathematics, Science and Technology Education (ICon-MaSTEd 2024), held from May 15-17, 2024, at Kryvyi Rih State Pedagogical University, Ukraine. The conference, organized in a hybrid format, brought together over 100 attendees from 9 countries, showcasing cutting-edge research and innovations in educational practices amid global challenges. The review synthesizes key themes and findings from 37 selected papers across various domains, including Mathematics Education, Science Education, Computer Science Education, and Educational Technology. Notable trends include the increased integration of artificial intelligence and digital technologies in education, the development of 21st-century skills, and adaptive strategies for education in crises. Particular attention is given to studies addressing the unique educational challenges faced in Ukraine, demonstrating the resilience and innovation of educators and researchers in conflict-affected regions. The paper highlights significant contributions in areas such as online learning environments, visual thinking in mathematics, AI applications in mental health education, and the design of university digital ecosystems.



1. Introduction

The **International Conference on Mathematics, Science, and Technology Education (ICon-MaSTEd)** stands as a prominent and esteemed platform for researchers, educators, professionals, policymakers, and practitioners to convene and exchange their cutting-edge research findings, innovative ideas, and practical applications in the realms of mathematics, science, and technology education. The conference also emphasizes technology-enhanced learning, encompassing various approaches such as blended learning, e-learning, ICT-based assessment, and mobile learning, among others, to enrich and advance educational practices (figure 1).

Initiated in 2001, ICon-MaSTEd has consistently fostered interdisciplinary collaboration, bringing together experts from diverse backgrounds to address the evolving challenges and opportunities in the fields of mathematics, science, and technology education. Over the years, the conference has witnessed substantial contributions from scholars and practitioners worldwide, propelling the domain forward with promising theories, models, tools, services, networks, and communications [1–5].

The XVI International Conference on Mathematics, Science and Technology Education (ICon-MaSTEd 2024) marks a significant milestone in the ongoing dialogue on educational innovation and advancement. Held against the backdrop of global challenges, including the ongoing conflict in Ukraine and the lingering effects of the COVID-19 pandemic, this year's conference underscores the resilience and adaptability of the educational community.

Organized by the Academy of Cognitive and Natural Sciences (ACNS) in collaboration with Kryvyi Rih State Pedagogical University, Kryvyi Rih National University, the Institute for Digitalisation of Education of the NAES of Ukraine, and Ben-Gurion University of the Negev, ICon-MaSTEd 2024 brought together a diverse group of researchers, educators, and practitioners from around the world. The conference, held from May 15-17, 2024, at Kryvyi Rih State Pedagogical University, Ukraine, adopted a hybrid format, accommodating both in-person and online participation to ensure inclusivity and global reach.

The primary objective of ICon-MaSTEd 2024 was to provide a platform for the exchange of cutting-edge research findings, innovative ideas, and practical applications in the realms of mathematics, science, and technology education. This year's conference placed a special emphasis on the integration of digital technologies, artificial intelligence, and innovative pedagogical approaches in addressing the evolving challenges in education.

The conference attracted over 100 attendees from 9 countries, including Ukraine, Norway, Israel, Greece, Philippines, Germany, Kazakhstan, Poland, and Slovakia. This international participation highlights the global relevance of the topics discussed and the collaborative spirit of the educational research community.

The program comprised a diverse array of subject areas, including Computer Science Education, Biology Education, Chemistry Education, Mathematics Education, Physics Education, Integrated Science Education, Educational Technology, and Technology Education.

A total of 61 submissions were received, each undergoing a rigorous peer-review process.

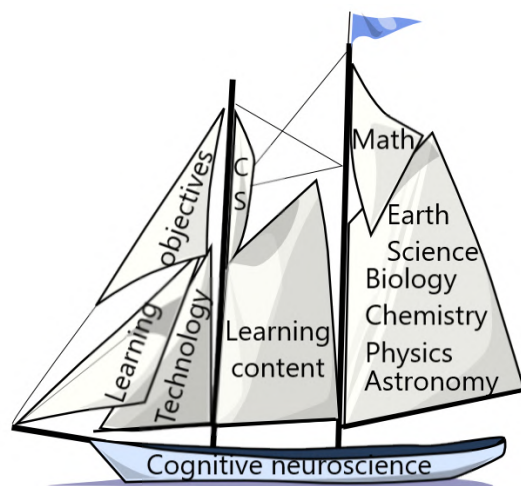


Figure 1. ICon-MaSTEd logo.

After careful deliberation, the program committee selected and accepted 37 high-quality papers for presentation at the conference. These papers represent the most impactful and innovative contributions to the field, covering a wide range of topics from theoretical frameworks to practical implementations of educational technologies.

The conference featured both invited talks and contributed presentations, providing a comprehensive outlook on the latest developments and emerging trends in mathematics, science, and technology education. The presentation format was thoughtfully structured to encourage interactive discussions and foster meaningful exchange of ideas among participants. Invited talks spanned 25 minutes, with a 15-minute presentation followed by a dedicated 10-minute session for questions and discussions. Other talks were allocated 15 minutes, comprising a 10-minute presentation segment and an additional 5 minutes for audience engagement and inquiry.

In light of the ongoing challenges posed by the conflict in Ukraine, special attention was given to topics addressing education in crises, the role of technology in ensuring educational continuity, and innovative approaches to maintaining academic excellence in challenging circumstances.

These proceedings compile the research presented at ICon-MaSTEd 2024, serving as a valuable resource for educators, researchers, and policymakers interested in the latest advancements in mathematics, science, and technology education. The papers included herein reflect the conference's commitment to fostering innovation, promoting interdisciplinary collaboration, and addressing the pressing educational challenges of our time.

The conference's detailed program and session information was made available to all attendees on the official website: <https://icon-masted.easyscience.education/2024/>. Additionally, to ensure wider accessibility and reach, video recordings of all talks were uploaded to the *Not So Easy Science* YouTube channel (<https://www.youtube.com/@NotSoEasyScience>).

As we present these proceedings, we invite readers to explore the diverse range of topics covered, draw inspiration from the innovative approaches discussed, and consider how these findings can be applied to enhance educational practices across various contexts and disciplines.

2. ICon-MaSTEd 2024 program committee

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- *Nataliia Valko*, Kherson State University, Ukraine [185, 186]
- *Nataliia Veretennikova*, Lviv Polytechnic National University, Ukraine [187]
- *Kateryna Vlasenko*, National University of Kyiv-Mohyla Academy, Ukraine [188–190]
- *Yuliia Yechkalo*, Kryvyi Rih National University, Ukraine [191–194]

3. Proceedings overview

3.1. Mathematics Education

The Mathematics Education section features seven papers that explore innovative approaches to mathematics teaching and learning at various educational levels.

Achkan et al. [195] present a case classification system for training prospective mathematics teachers. They identify key characteristics for classifying cases, such as complexity level, completion time, problem scope, and presentation method. The authors provide examples of cases that can be used in teaching methodological disciplines to mathematics education students.

Vlasenko et al. [196] investigate the use of stochastic matrices in teaching the topic of eigenvalues and eigenvectors in linear algebra courses. Through an experiment with students in different specialities, they demonstrate how problems based on Markov chains can improve students' skills and understanding of this important mathematical concept.

Semenets et al. [197] delve into the content, components, and typology of structural-mathematical thinking. They propose a developmental-conceptual model for teaching mathematics that fosters students' theoretical thinking skills. The authors experimentally validate the effectiveness of their methodology for enhancing structural-mathematical thinking in prospective mathematics teachers.

Pylypenko and Kramarenko [198] present a structural-functional model for developing STEM competencies in students of professional pre-higher education institutions through mathematics education. The model incorporates motivational, content, activity, and diagnostic components. The authors provide examples of STEM projects and learning activities that can be implemented using their approach.

Voievoda et al. [199] examine the geometric properties of metric spaces and propose using the dynamic geometry environment GeoGebra 3D for visualizing concepts such as rectilinear and

planar point configurations. They argue that this approach can help students better understand the abstract concepts of metric geometry.

Kuzmich et al. [200] introduce an analytical and geometric interpretation of planar point arrangements using methods from metric geometry. They demonstrate how the GeoGebra dynamic mathematics software can be used to model and visualize these configurations in Cartesian coordinate systems, making the concepts more accessible to students.

Horoshko et al. [201] focus on solving problems with parameters using a digitized approach. They analyze various computer mathematics systems, such as GeoGebra, Wolfram—Alpha, Maxima, SageMath, and GRAN1, in terms of their suitability for graphical and analytical problem-solving. The authors provide methodological recommendations for using these tools in teaching mathematics.

3.2. Physics and Astronomy Education

The Physics and Astronomy Education section features eight papers exploring various aspects of teaching and learning in these domains.

Malchenko et al. [202] investigate the use of visualization technologies, specifically the Universe Sandbox 2 simulation software, to study the probability of life on exoplanets. The research demonstrates the effectiveness of interactive simulations in enabling students to model and analyze conditions necessary for life on exoplanets.

Felucidario and Delos Santos [203] present a study on enhancing student performance through laboratory-based instruction, focusing on concepts of relative density and buoyancy of liquids. The findings reveal significant improvements in student performance and positive perceptions towards laboratory activities.

Kaliampos et al. [204] explore the mental representations of 5-6 year old children regarding coagulation phenomena and the impact of a storytelling teaching intervention. The study highlights the potential of narrative approaches in helping young children construct precursor models compatible with scientific knowledge.

Pacala [205] examines the effectiveness of laboratory-based instruction in teaching fundamental concepts of physics. The research underscores the significant role of hands-on experiments in enhancing student understanding and performance.

Abdulayeva [206] conducts rapid foresight research to identify trends and directions in physics teaching, including the integration of artificial intelligence. The study emphasizes the importance of involving students in the foresight process to inform future teaching practices and strategies.

Batsurovska et al. [207] present a technology for online control of educational results in the unit “Electricity” within a blended learning context. The findings demonstrate the effectiveness of the developed technology in improving student knowledge and skills.

Velychko et al. [208] analyze various computer modelling tools for studying the interaction between charged particles. The research compares the advantages and limitations of different software packages and programming languages for implementing computer models in physics education.

3.3. Earth Science Education

The Earth Science Education section contains one paper focusing on using mapping technology with ArcGIS tools to train geography students.

Tsidylo et al. [209] present a study on developing professionally oriented tasks to teach future geography teachers mapping technology using ArcGIS services. The authors emphasize the importance of geoinformation technologies in modern geography education and the need for students to acquire practical skills in using GIS software.

The paper outlines the main aspects of introducing professionally oriented tasks into the educational process of pedagogical institutions. Educational and methodological guidelines for

studying and using mapping technology with ArcGIS tools are developed for students and future geographers.

As a practical application, the authors demonstrate the creation of a series of maps depicting various indicators of Ukraine's regions, such as a cartogram of population distribution, using the quantitative background method. The data for these maps is sourced from the State Statistics Service of Ukraine and the Main Statistical Offices of Ukrainian regions.

Geography students are used to experimentally verify the effectiveness of using professionally oriented tasks to learn ArcGIS mapping technology. The results show an increase in students' abilities according to specified criteria: motivational, cognitive, and personal-reflective.

The authors conclude that the mapping approaches presented, based on the implementation of professionally oriented tasks, allow students to apply their acquired knowledge and skills, enabling them to adapt flexibly to situations arising in their future professional activity as geographers.

This paper highlights the importance of integrating GIS technology and practical, profession-oriented tasks into the training of future geography teachers, equipping them with valuable skills for their field.

3.4. Computer Science Education

The Computer Science Education section features seven papers exploring various aspects of teaching and learning in this domain.

Shpakov et al. [210] conduct an ontological analysis of business process modelling in higher education institutions based on an electronic document management system. They study the main business processes, analyze the structure, functions, and information flows, and develop an ontological model of interaction between subjects and objects. The model enables the assessment of system efficiency and the prediction of critical processes that may impact decision-making and institutional functioning.

Pavlenko et al. [211] present a method for developing teamwork skills among students in the "Professional Education. Computer Technology" program through the use of digital tools and a collective scientific research lifecycle. The proposed iterative model consists of preparatory, analysis, storage, organization, sharing, reuse, citation, and data creation stages. An experimental study confirmed the effectiveness of the method in improving students' teamwork abilities.

Balyk et al. [212] investigate the use of STEM technologies in training competitive computer science teachers to meet social needs and challenges, particularly during wartime in Ukraine. Key components of a STEM teacher training model are identified, and an experimental study determines students' attitudes towards STEM technologies. The necessity of ensuring high teacher qualifications for effective STEM education is substantiated.

Leshchuk et al. [213] implement a STE(A)M approach through Scratch projects to foster students' creativity and problem-solving skills. The developed "Creative Self-Fulfilment in Scratch" course extends into projects in algebra, geometry, physics, and musical culture, demonstrating the unity of technology and creativity. Each project serves as an independent development tool for students.

Bilousova et al. [214] highlight the importance of engaging pre-service IT specialists in interdisciplinary projects to understand the mathematical foundations and algorithmic nature of coding tasks. A model for such projects is described, focusing on the development of student's awareness of the value of mathematical knowledge in their professional activities. A survey and monitoring program revealed positive changes in students' perceptions.

Kolhatin et al. [215] present a distance learning technology for the "Robotics Fundamentals" course, combining virtual simulations and remote-controlled physical robots. Students progress

from modelling and testing algorithms in a virtual environment to implementing them with real robots, gaining practical experience in robotics system development and software engineering.

Semerikov et al. [216] propose a methodology for teaching the development of web-based augmented reality applications with integrated machine learning models. The three-step approach involves integrating standard TensorFlow.js models, creating custom image classification models with Teachable Machine, and modifying WebAR applications to utilize the exported models. The methodology aims to incrementally introduce machine learning integration and inspire ideas for enhancing educational content.

3.5. Integrated Science Education

The Integrated Science Education section features six papers exploring interdisciplinary approaches to teaching science.

Valko and Kushnir [217] present their experience conducting long-term integrated robotics projects in summer camps, scientific studios, and extracurricular clubs. The projects combine various activities to explore topics and conduct scientific and technological research. The authors emphasize the importance of mastering robotics technology and understanding the principles of operation to prepare children for life in a high-tech world. The foundation for studying and applying these technologies is mathematics, physics, engineering, and programming. STEM education, aimed at developing in-demand competencies and increasing motivation to study challenging subjects, is of particular importance. The article shares the experience of a volunteer project teaching robotics to Ukrainian children, detailing organizational conditions, typical difficulties, project examples, and lesson scenarios.

Ludovice and Delos Santos [218] study the absorbance of methyl orange (MO) dye using an adapted and modified photoresistor-based photometer. They aim to improve the stability of the reference setup while maintaining accuracy. The methodology includes photometer fabrication, MO sample preparation, and evaluation of molar absorptivity. Results show that the estimated molar absorptivity is close to the literature value, with a 1.44% error. This demonstrates the modified photometer's effectiveness, supported by method repeatability measurements. The device may be helpful in teaching light absorption as an alternative to the "black box" approach and for exploring purified natural dyes with solar cell applications.

Fedorets et al. [219] reveal the phenomenology of cognitive transformations in the human-artificial intelligence interaction based on their "Concept of cognitive multi-channel Human-Computer interaction". The interaction is implemented through the formation of typical cognitive phenomena, considered as relatively independent types of interactions, stages, strategies, channels, and ontologies. Seven types of cognition are distinguished. Identifying these types aims to represent the interaction as a complex, dynamic, multidimensional, multichannel intellectual system. A study among university students determined the cognitive specificity of the interaction. Analysis of test answers and cluster analysis results showed the dominance of the "orientational-cognitive" type, indicating significant initial interest in AI technologies. The even distribution of other cognitive types correlates with respondents having developed different types of cognition.

Suchikova and Kovachov [220] explore the integration of Nanoart within the STEAM education framework, highlighting its role in enhancing interdisciplinary learning. Through a project-based learning initiative, students specializing in "Applied Physics and Nanomaterials" engage in creating nanostructures via electrochemical etching and transforming them into Nanoart. This exemplifies the seamless integration of STEAM components and deepens students' understanding. The article details each project phase, illustrating how students navigate nanoscience complexities and apply interdisciplinary knowledge to produce artistic and scientific outcomes. By transforming abstract concepts into visually stimulating Nanoart, the project encourages creative thinking and innovation. It demonstrates how integrating art

into STEM can make scientific education more accessible and engaging, attracting a broader array of students.

Levytska et al. [221] present the development of virtual laboratory work to determine the dispersed composition parameters of dust for teaching environmental protection technologies to bachelors. The authors analyze publications on using virtual laboratories in universities and emphasize their role in supporting modern educational approaches, stimulating learning, and enabling more effective material mastery. The article describes an example of developing laboratory work as a web application with a user-friendly interface and data saved into a database. Students can work at their own pace, repeat experiments, and adapt their learning approach. The virtual laboratory is relevant for distance learning.

Homeniuk et al. [222] propose a methodology for increasing mathematics students' motivation to implement STEM education elements through teaching mathematical modelling in elementary mathematics. The three-stage methodology involves students constructing, investigating, and interpreting mathematical models while solving tasks related to Science, Technology, Engineering, and Mathematics. In the second stage, students perform operations with mathematical models to solve integrative tasks combining all STEM components. The third stage focuses on constructing, analyzing, and solving STEM-related applied problems from various elementary mathematics sections. The methodology combines collective, individual, and group work. A survey confirmed the effectiveness of STEM-oriented activities like STEM-hackathon, STEM-quest, and STEM-project in developing students' understanding of mathematics' role in STEM fields and their ability to work in teams.

3.6. Educational Technology

The Educational Technology section features eight papers exploring various aspects of digital transformation in education and the application of innovative technologies in teaching and learning processes.

Semerikov et al. [223] present a bibliometric analysis of research articles published in Educational Technology Quarterly (ETQ) from 2021-2023. Their study aims to identify key themes and changes in focus within the educational technology domain over this period. The authors analyze 72 research articles, examining patterns in keywords, temporal trends, and geographic distribution of authors. The findings reveal emerging topics such as digital competence, blended learning, and cloud-based learning environments. The study also highlights the impact of the COVID-19 pandemic on research priorities and the growing interest in digital skills development.

Symonenko et al. [224] investigate the application of chatbots for enhancing the communication skills of IT specialists. The authors developed a chatbot named BEbot (Business English bot) to support a Business English course for IT professionals. The study demonstrates how chatbot technology can be effectively integrated into language learning, particularly for developing business communication skills. The results show an improved understanding of business English concepts and increased student engagement through interactive chatbot-based learning.

Shumeiko and Osadcha [225] explore the application of artificial intelligence in higher education institutions for developing the soft skills of future IT specialists. The study focuses on the use of AI tools in teaching humanitarian subjects, particularly in forming project competence. The authors present a system of quality factors for video-based microlearning technology and discuss the effectiveness of AI-enhanced learning in developing soft skills such as communication, negotiation, and problem-solving.

Hlazunova et al. [226] examine microlearning technology based on video content, discussing its advantages, methodology, and quality factors. The study investigates the impact of video-oriented e-courses and microlearning technology on learning effectiveness. The authors develop

a procedure for microlearning based on video content and identify critical factors affecting the quality of e-courses for microlearning.

Buinytska et al. [227] present a theoretical exploration of university ecosystem design under conditions of digital transformation. The paper analyzes international and Ukrainian legal acts related to the digital transformation of higher education and proposes a model for an open university ecosystem. The authors describe the digital campus of Borys Grinchenko Kyiv Metropolitan University as a current stage of digital transformation and a starting point for open university ecosystem design.

Klochko et al. [228] discuss the formation of visual thinking of students in technical universities in the context of higher mathematics education. The study explores the use of visualization techniques in teaching mathematics and presents examples of how visual representations can enhance understanding of complex mathematical concepts.

Bondar et al. [229] investigate the role of AI in enhancing mental health and productivity amidst Ukraine's challenges. The paper explores the convergence of human intelligence with artificial intelligence in the realm of mental health education, particularly within Ukrainian educational institutions following the pandemic and amid wartime conditions.

Hapon-Baida and Derkach [230] present an educational technology for the formation of project competence for engineering students. The study describes the development and implementation of a project-based learning approach to enhance project competence among engineering students.

4. Conclusion

The XVI International Conference on Mathematics, Science and Technology Education (ICon-MaSTEd 2024) has once again proven to be a vital platform for researchers, educators, and practitioners to share their latest findings and innovations in education. This year's conference, held in challenging circumstances due to the ongoing conflict in Ukraine, demonstrated the resilience and dedication of the academic community to advancing knowledge and improving educational practices.

The conference proceedings encompass a wide range of topics across various disciplines, reflecting the multifaceted nature of contemporary education. From mathematics and science education to computer science and educational technology, the papers presented offer valuable insights into current trends, challenges, and innovative solutions in these fields.

A notable trend observed throughout the proceedings is the increasing integration of digital technologies and artificial intelligence in education. This is evident in papers discussing the use of AI in mental health education, the application of chatbots for language learning, and the development of digital ecosystems for universities. These studies highlight the potential of technology to enhance learning experiences, improve accessibility, and prepare students for a rapidly evolving digital world.

Another significant theme that emerged is the focus on developing essential skills for the 21st century. Several papers addressed the formation of critical thinking, visual thinking, and project competence, emphasizing the importance of these skills in preparing students for future challenges in their academic and professional lives.

The conference also strongly emphasised addressing the unique challenges faced by educators and students in Ukraine. Papers exploring the adaptation of educational practices during wartime and the use of technology to maintain educational continuity in difficult circumstances provide valuable insights for the global academic community.

The proceedings reflect a growing interest in interdisciplinary approaches to education. Studies combining elements from different fields, such as the integration of art in STEM education or the application of psychological principles in computer science education, demonstrate the potential of cross-disciplinary collaborations in enhancing educational outcomes.

The quality and diversity of the research presented at ICon-MaSTEd 2024 underscore the conference's significance as a forum for exchanging ideas and advancing the field of education. As we look to the future, the insights gained from these proceedings will undoubtedly contribute to shaping more effective, inclusive, and innovative educational practices.

We extend our gratitude to all the authors, reviewers, organizers, and participants who contributed to the success of ICon-MaSTEd 2024. Their collective efforts, especially in the face of challenging circumstances, have resulted in a valuable contribution to the field of education. We look forward to seeing how the ideas and findings presented in these proceedings will influence future research and practice in mathematics, science, and technology education.

We hope all participants enjoy this conference and meet again in a more friendly, hilarious, and peaceful way, ICon-MaSTEd 2025. The next meeting in the series is the XVII International Conference on Mathematics, Science and Technology Education, 2025, Kryvyi Rih, Ukraine (<https://icon-masted.easyscience.education/2025/>).

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The case classification and their development for would-be mathematics teachers' training

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6th**

Showcase your science!

The case classification and their development for would-be mathematics teachers' training

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Abstract. The article looks into the issue of the case classification for the training of Mathematics teachers. The analysis, which was carried out, and the survey of 47 University teachers of methodical disciplines allowed to highlight the classification features of cases in the process of teaching methodical disciplines: the amount of time to complete, the way of presentation, the level of complexity and the breadth of the covered problem. Classifying cases by the amount of time for their implementation contributed to the separation of mini-cases, medium-term cases, and long-term cases. Classification by the method of presentation of cases in the process of studying methodical disciplines ensured their use in printed (handwritten) form, multimedia presentation of cases, and video cases. According to the level of complexity, the cases were divided into reproductive-training, partial-research, and creative-innovative cases. Thematic and integrated cases ensured the breadth of coverage of the problem during the teaching of methodical disciplines. The article presents general requirements for the selection and development of cases in the process of studying methodical disciplines. These requirements are based on the principles of accessibility, scientificity, contextuality, systematicity, methodological expediency, and practical orientation. The classification and specific requirements became the basis for the development of cases that can be used in the process of teaching methodological disciplines of would-be Mathematics teachers.

1. Introduction

1.1. Problem statement and its topicality substantiation

As noted in the Standards for Training Mathematics Teachers, developed by the Association of Mathematics Teacher Educators [1], an effective Mathematics teacher must take into account the existing social contexts of learning, and actively use and adapt existing innovative developments to the needs of a specific group of students. As rightly pointed out by Barkai [2] and Mainali [3], the use of the case method provides would-be Mathematics teachers with ample opportunities to acquire and analyze practical experience. It is the analysis and modeling of specific situations that allow a would-be Mathematics teacher to be trained to find effective ways to overcome problems in teaching Mathematics, to correspond to society's order.



The basis of the professional training of would-be Mathematics teachers is methodological disciplines, such as Methods of Teaching Mathematics, Technologies of Teaching Mathematics, and several disciplines of students' free choice [4]. It is in the process of learning methodical disciplines that students get acquainted with the fundamental foundations of the organization of Mathematics education, learn to combine traditional and innovative types, methods, techniques, and technologies of pedagogical activity, reflect on their own experience, and analyze how to correct their professional activity [5, 6]. Therefore, the problem of using the case method in the process of teaching methodical disciplines is relevant, which involves the classification and development of cases that should be used in the training of would-be Mathematics teachers.

1.2. Analysis of the latest research and publications

The implementation of the case method is associated with Harvard University. Research by Amaratunga and Baldry [7], Feagin et al. [8], Tellis [9] are devoted to generalized theoretical positions of the case method in education. Amaratunga and Baldry [7] substantiated the importance of using the case method in education. We agree with scientists that the case method should be used only after students have acquired a certain system of basic knowledge. Feagin et al. [8] studied the methodological foundations of the implementation of the case method and gave examples of its use in the process of training specialists in the social sphere. We took into account the scientist's opinion regarding the methodology of creating and conditions for using cases in the educational process. As Tellis rightly noted [9], the case should be focused on the organization of students' quasi-professional activities.

Easton [10] and Schritteser [11] were interested in organizing such activities during teacher training. Schritteser [11] analyzed the importance of using the case method for organizing reflection and correction by teachers of their professional activity. We were fascinated by the scientist's opinion that cases should be created taking into account the level of practical abilities of teachers and be oriented towards professional self-improvement. We share the views of Easton [10] about the importance of the case method in the process of training teachers for professional activities. We took into account the recommendations proposed by Easton [10] regarding the use of the case method in the process of teacher training. Our research follows recommendations regarding the orientation of cases to the development of critical thinking of active teachers and the need to have several ways of solving the case. To sum up, all scientists agree that the systematic use of the case method helps to increase the readiness of working and would-be teachers to effectively perform professional activities and to find new non-standard, creative ways to solve educational tasks.

The studies of Gay [12], Yuan [13], Puri [14], Takker [15], Barkai [2], Yilmaz [16], Li and Yang [17], Smith and Friel [18] are devoted to the issue of using the case method in teaching Mathematics. Gay [12] and Puri [14] substantiated the importance of using the case method to increase students' motivation to learn Mathematics. Li and Yang [17] investigated similar aspects of increasing motivation to learn Mathematics, as well as increasing the level of students' competencies in the process of studying the course 'Introduction to Mathematics'. We agree with scientists that the case should be formulated in the form of a problem situation. Crucial for our research are the opinions expressed in both studies regarding the feasibility of using the case method at different stages of education. Our study relied on the opinions highlighted in the works of Yuan [13] and Yilmaz [16]. The scientists substantiated the effectiveness of using the case method for the training of Elementary School Mathematics teachers and identified separate provisions for the construction of cases. Takker [15] and Smith and Friel [18] proved that learning based on specific situations or so-called contextual learning is one of the most productive methods. The idea of scientists was taken into account, according to which the use of cases, among other things, lays the foundations for further teachers' self-improvement through the analysis of practical activities.

The use of the case method in the training of a mathematics teacher is a paramount component of the didactic training of the teacher. Various aspects of the Mathematics teacher didactic training are devoted to the research of Guérios and Gonçalves [19], Breda et al. [20], Blanco et al. [21], Nurdiana et al. [22], Achkan et al. [23].

The opinions of Guérios and Gonçalves [19] and Achkan et al. [23] are interesting for our research, which substantiated the expediency of organizing didactic training of would-be Mathematics teachers starting from the first year of study. Such preparation using the case method lays the foundations for the organization of quasi-professional activities in senior courses. It follows the views of Breda et al. [20] that the students' didactic knowledge should be formed in the process of contextual activity. This didactic knowledge is a prerequisite for the formation of the ability for reflection of Mathematics teachers and self-improvement in professional activity. While researching, we relied on the work of Nurdiana et al. [22]. The scientists investigated the issue of the formation of didactic competencies of would-be Mathematics teachers while studying Geometry and emphasized the importance of acquiring subjective contextual experience. Blanco et al. [21] substantiated the importance of methodological and mathematical training for primary school teachers. As the scientists rightly noted, it is the systematic selection of practice-oriented teaching methods that creates the basis for training a competitive and capable teacher. One such practice-oriented method is the case method.

The same idea is supported by Straesser [11] and Vlasenko et al. [24] according to which the study of mathematics didactics is one of the key areas of training would-be mathematics teachers. At the same time, as Marinković and Đokić [25] rightly note, the main goal of the course 'Didactics of Mathematics' and other didactic disciplines is to promote the formation of independent and creative practicing teachers. We share the opinion of Barkai [2] regarding the effectiveness of using the case method for training Mathematics teachers and the main key element of this method is the case.

The analysis of the given views of scientists made it possible to formulate the concept of a case. By the case, it will be understood the educational problem or the situation that may contain additional facts, descriptions, and opinions. Solving such a situation creates conditions for the organization of students' quasi-professional activities. That is, the situation is realistic, and its discussion allows for modeling the content of future pedagogical activity. The case assumes the presence of at least two ways of solving the problem situation. Working with a case requires students to use their knowledge, abilities, skills, subjective Mathematics experience, and mathematics teaching methods. The educational situation is focused on the development of creative personality qualities of would-be mathematics teachers.

Effective implementation of the case method in teaching methodical disciplines requires a convenient case classification. It agrees with Zhang et al. [26], who believe that classification is a crucial method of pedagogical research. The effective classification of methods (students, technologies) is the basis for building an effective education system.

The researchers Baxter and Jack [27], Crowe et al. [28] Yin [29], and Sinha [30] considered the issues of case classification in the education of students of various specialties. Interestingly our study is the opinion of Baxter and Jack [27], who offered a universal case classification for training students, graduate students, and researchers. The scientists included Explanatory, Exploratory, Descriptive, Multiple-case studies, Intrinsic, Instrumental, and Collective types of cases. The given classification helped us to distinguish two classification characteristics of cases in Mathematics teacher training. We were fascinated by the idea of Tortajada-Genaro [31] regarding the division of cases by execution time. At the same time, the scientist analyzed in detail and substantiated the expediency of using only mini-cases. Our study took into account the results of Crowe et al. [28]. It is about views on this type of case as explanatory one. In general, the classification of cases developed by scientists (internal, explanatory, collective, instrumental) is difficult to use because it does not have a single basis for classification. We share the ideas

of Sinha [30] regarding the expediency of distinguishing Particularistic and Heuristic cases (in addition to them, the scientist also distinguishes Descriptive). Similar views are held by Yin [29], who offered to distinguish search, descriptive, and explanatory cases. Thus, none of the analyzed case classifications is multifactorial and does not take into account the specifics of the would-be Mathematics teacher training. This makes the problem of building a multifactorial case classification relevant.

The aim of the study is a theoretical generalization of the scientists' views and a survey of teachers of methodical disciplines to build classification and develop cases for the training of would-be mathematics teachers.

2. Methods

We invited university lecturers from Berdyansk State Pedagogical University, Kryvyi Rih State Pedagogical University, Vinnytsia Mykhailo Kotsiubynskyi State Pedagogical University, Pavlo Tychyna Uman State Pedagogical University, The Bohdan Khmelnytsky National University of Cherkasy, Ternopil Volodymyr Hnatiuk National Pedagogical University, and Donbass State Engineering Academy to take part in the survey using Google Forms. The survey involved 64 teachers. It worked out the issue of using cases in the process of teaching methodical disciplines. The questionnaire contains 6 questions that require the choice of an answer. One of the questions requires its version of the answer in addition to the choice proposed. The first question made it possible to find out how actively teachers use the case method in the teaching of methodological disciplines. The second question helped to highlight the main classification characteristics of the cases. The other four questions helped to identify the types of cases that should be used within each of the classification characteristics.

The selection of cases in the classification process should be carried out taking into account such requirements.

1. Availability. The choice of the case type should correspond to the level of methodological competence of students, and readiness to produce creative solutions.
2. Scientism. The cases are aimed at students mastering the scientific foundations of general and partial methods of teaching Mathematics, forming the ability to systematically apply methods, forms, and technologies of learning.
3. Systematicity. The use of cases in the process of teaching methodical disciplines should occur constantly, and systematically, supplementing the traditional methods of teaching methodical disciplines.
4. Contextuality and practical orientation. Cases in the process of teaching methodical disciplines as closely as possible (simulate) situations that would-be teachers will encounter in their professional activities.
5. Methodological expediency. The choice of the case type is related to the type of class and the goal pursued by the teacher. Taking into account the requirements described above, the classification and survey of teachers contributed to the structuring of cases according to such characteristics in the process of training the would-be Mathematics teacher (figure 1).

By the amount of time for execution, cases are divided into mini-cases, medium-long cases, and long-term cases. Mini-cases require 15 to 25 minutes to find solutions. It is possible to find solutions and discuss at least two mini-cases during one class. Medium-long cases require from 30 minutes to 1 hour to find solutions. Usually, one medium-long case or three such cases in paired classroom sessions are solved and discussed during the class. Long-term cases require more than an hour to find solutions. They are used for extracurricular students' self-work.

It is advisable to use mini-cases as a means of creating a problem situation during lectures on methodical disciplines and in the process of practical class. It is appropriate to use medium-

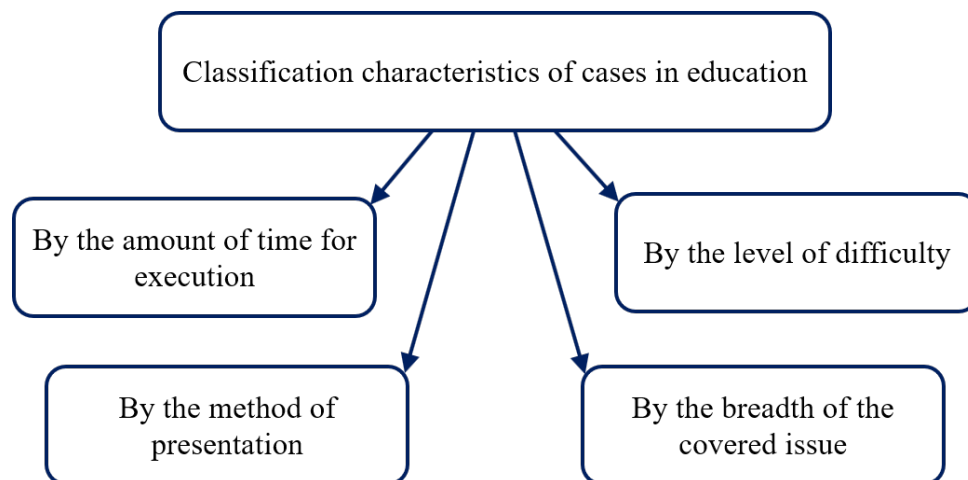


Figure 1. Characteristics underlying the case classification.

long cases in the process of practical classes on methodical disciplines. There is a sense to offer long-term cases to students for extracurricular individual or collective work.

According to the level of complexity, the cases are divided into reproductive-training, partial-research (heuristic) and creative-innovative. Reproductive and training cases contain structured information, a standard situation, which provides for the presence of two or three models of pedagogical activity to achieve an optimal result. Information in partial search (heuristic) cases is not exhaustive. Such cases require additional analysis and modification of standard models of pedagogical activity. They may contain some absolutely unnecessary facts for finding a solution, information that distracts attention from key point. The task in creative and innovative cases requires students to propose a new, creative solution based on the acquired knowledge, skills and subjective experience.

The choice of the case type by the level of complexity depends on the purpose of its use and the level of preparation of the students. For example, it is advisable to use reproductive training cases in lectures on methodical disciplines to create a problem situation. There is a sense of starting separate practical classes with a collective discussion of such cases. It is appropriate to use partial research cases in lectures on certain topics, provided the students have a high level of preparation. It is also possible to use partial research cases during practical classes for both face-to-face and group work. It is advisable to offer creative and innovative cases in practical classes and for self-work outside the classroom to individual students.

By the method of presentation, cases were divided into cases in printed (handwritten) form, multimedia presentation, and video cases. The choice of presentation method depends on the form of education and the teacher's technical capabilities. During distance learning, it is worth giving preference to two extreme types of cases. During face-to-face training in classrooms, it is appropriate to offer individual cases, mostly short ones, in printed form. At the same time, if technical capabilities are available, multimedia presentation and video cases should prevail.

Based on the breadth of the covered problem, cases are divided into thematic and integrated ones. Thematic cases are related to the method of introducing concepts, proving statements, and studying a certain content line of the high Mathematics course. Integrated cases require reliance on knowledge, skills, and subjective experience of one or more methodological disciplines. It is advisable to use thematic cases lecturing methodical disciplines to create a problem situation. Also, their application is useful during practical classes devoted to considering methods of teaching Mathematics. It is appropriate to use integrative cases when students have already studied the basic course of Mathematics teaching methods and are mastering other methodical

disciplines. Also, their application is useful in final practical classes.

Note that a case from methodical disciplines can refer to cases of several types. For example, a reproductive training, thematic mini-case is presented in printed form.

Case 1 (reproductive and training, thematic, mini-case presented to students in printed form). In the next semester, you will have an Internship, during which you will conduct classes. It is given an example of your colleague's activity. Intern student Petrenko Oleksiy taught geometry classes in the seventh grade. These classes were devoted to the study of the triangles' equality. All of them were conducted according to the same scheme: formulation of the theorem, drawing, quick proof on the board (explanations are minimal), and transition to solving problems on the theorem application. Do you think this approach is methodologically appropriate? Describe the possible methodical techniques for familiarizing students with proofs of the theorem of the triangles' equality. Suggest your plans for conducting such classes.

Case 2 (reproductive and training, thematic mini-case, presented in printed form). In the Algebra class, the teacher asked the students to calculate the value of $\cos 15^\circ$. Suggest different methods of calculating this expression depending on the profile of the class. In the process of learning, what topics can such tasks be used? What role does performing calculations in different ways (techniques) play in learning Mathematics?

Case 3 (heuristic, medium-long, thematic, presented in printed form). During the Algebra class, the teacher offered the students to solve the problem: the amount of tourist tax receipts in August 2019 increased by 10% compared to July tourist tax receipts and amounted to UAH 510,000 (the statement is not finished). Formulate several problems using the given preamble. These problems can be used in the process of studying different Algebra topics while learning Mathematics in schools. List these topics and typical mistakes that students may make when solving such problems.

Case 4 (creative and innovative, thematic, long-term, presented in the form of a multimedia presentation). The young Mathematics teacher was summoned by the director of the school: 'The day after tomorrow we are expecting distinguished guests at our school who will check the organization of extracurricular activities. And you just have group classes in the seventh grade. I hope you will support the high image of the school and pleasantly surprise your colleagues with innovative approaches to organizing group work'. It is expected you suggest a possible title for a Maths club that matches the innovative trends in Mathematics education, and present a class plan using innovative learning technologies.

Case 5 (heuristic, integrated, medium-long, presented in the form of a multimedia presentation). The teacher started the Geometry class with a story giving an example of a construction situation. While building, walls, in the absolute majority, are created vertically. There are exceptions, but the construction of such buildings is associated with significant difficulties and increases their cost. A plumb line is used to check the verticality of the walls at the construction site. This is a device consisting of a thin thread and a load on it. The question may arise: is such a check sufficient? Which topic of a school Mathematics course can use this story as the introduction? What technology does the Math teacher use to start the class this way? Offer methodological recommendations for the continuation of the class (10-12 minutes). Describe other methodological approaches within the framework of technology used by the teacher. Illustrate one of them using the example of other topics of the Mathematics course of a specialized school.

Case 6 (heuristic, long-term, integrated, presented in printed form). A young Mathematics teacher got a position at a school that works on the system of concentrated education. On the next day, the teacher will have to conduct three Mathematics classes in a row in the tenth grade of the chemical and biological profile. He decided to conduct the first Mathematics class of the school year in the form of a lecture. He took as a pattern a traditional lecture, which he repeatedly attended during his studies at the university. Evaluate the methodical expediency of choosing

this form of conducting the class. Offer your vision regarding the types and methodological features of the organization of this kind of class. Develop a class plan for one of them.

3. Results

The results of the online survey of university teachers of methodological disciplines, which was carried out during the research, proved the following. The majority of respondents use (57.5%) or plan to use (29.7%) the case method in the process of teaching methodological disciplines. Among the key characteristic features of case classification, the respondents attributed the level of complexity (71.9%), the amount of time for implementation (64.1%), the breadth of coverage of the problem (60.9%), the method of presentation (51.6%) and the purpose of the activity (45.3%). The results of the questionnaire regarding the use of the case method in the process of studying methodical disciplines and the characteristic features of the cases are shown in figure 2 and figure 3.

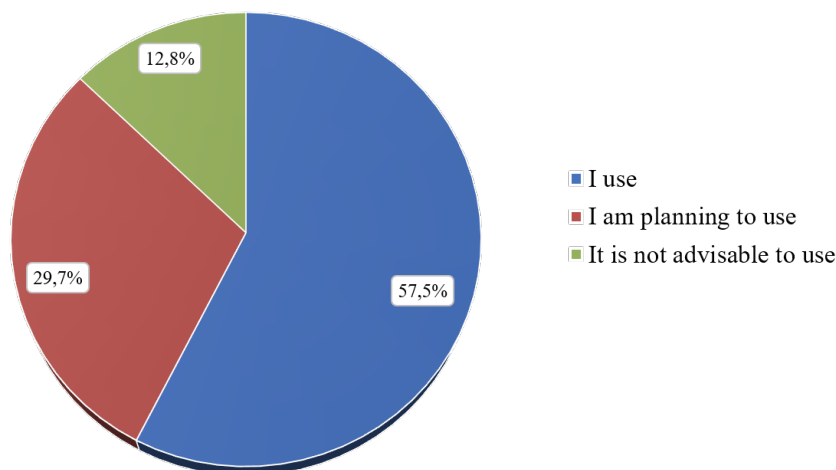


Figure 2. Respondents' answers regarding the use of the case method.

Also, according to each classification characteristic, teachers were asked to rate their attitude towards a certain type of case on a ten-point scale. According to the level of complexity, the partial research (7.5) and reproductive-training (7.1) cases received the highest average score from the respondents. Creative and innovative cases scored 6.2 points (figure 4).

According to the amount of time spent on the case, the teachers consider medium-long (7.6 points) and long-term cases (7.3 points) to be the most appropriate. The mini-cases received a slightly lower score of 6.2 points (figure 5).

In terms of the breadth of the covered problem, teachers preferred thematic cases (8.2). Integrative cases received an average score of 6.9 (figure 6).

Based on the method of presentation, according to respondents, the cases were distributed as follows (figure 7): in the form of a multimedia presentation (8.0), cases in printed form (7.1), and video cases (7.4).

Thus, the analysis of the received answers from the interviewees made it possible to clarify the classification characteristics of the cases and to distinguish the types of cases in the teaching of methodical disciplines.

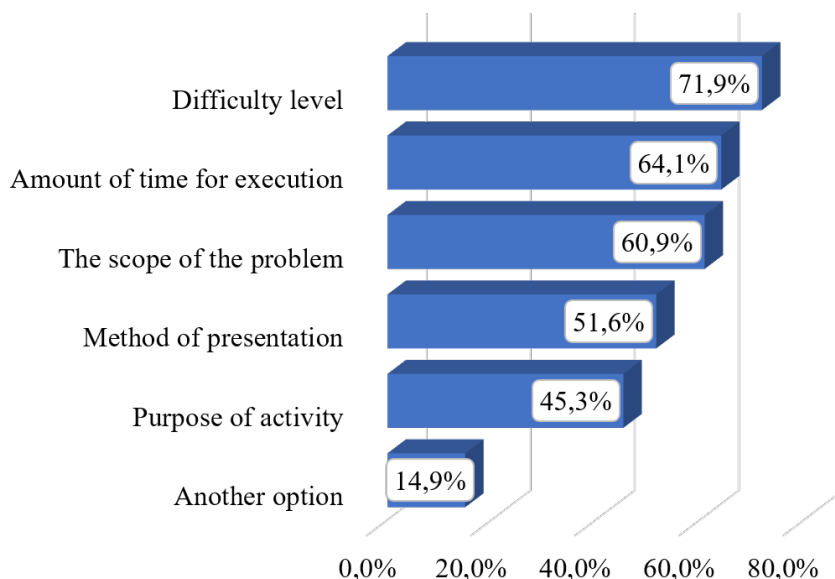


Figure 3. Respondents' answers regarding the expediency of using the case method.

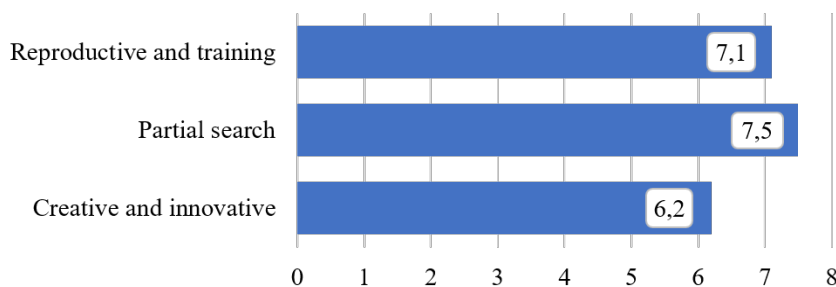


Figure 4. Teachers' attitude to types of cases by level of difficulty.

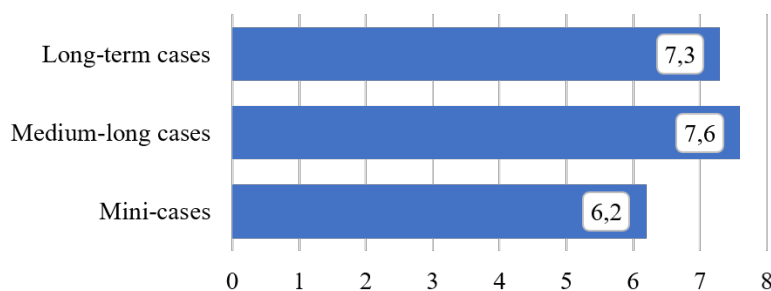


Figure 5. Teachers' attitude to types of cases by the amount of time for completion.

4. Discussion

The analysis of the scientists' papers Baškarada [32], Kelch and Malupa-Kim [33] confirmed the relevance of using the case method in the training of would-be Mathematics teachers. Also, these studies contributed to clarifying the classification of cases that should be used in the process of such training. We were fascinated by the idea of Kelch and Malupa-Kim [33], according to

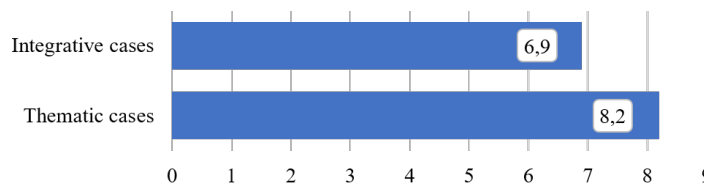


Figure 6. Teachers’ attitude to types of cases by the breadth of coverage of the problem.

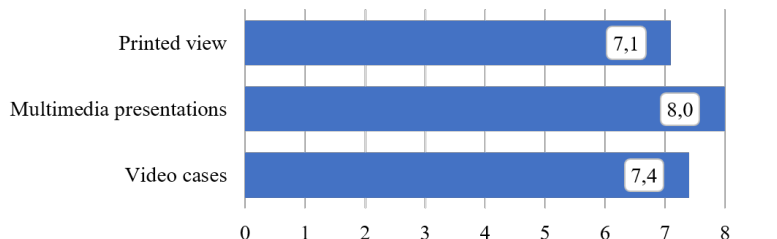


Figure 7. Teachers’ attitude to types of cases by the presentation method.

which the case method is the basis for the formation of the teacher’s professional competence. We fully agree with the opinion of Baškarada [32] regarding the expediency of classifying cases depending on the didactic purpose of the class. At the same time, we believe that the specifics of Mathematics as a science and the peculiarities of Mathematics didactics should be taken into account in the process of classifying cases.

The classification was chosen as the research method. The idea of Shigang and Sheng [34] that classification is an important and effective tool of pedagogical research is taken into account. At the same time, the development of the classification was coordinated with the opinion and experience of teachers of methodical disciplines. A questionnaire was created for this purpose. The need for its development is consistent with the studies of Nurdiana et al. [22], [12], Crowe et al. [28], and Lovianova et al. [35]. The analysis of respondents’ answers made it possible to single out the main qualifying characteristics of the cases and the types of cases within each characteristic.

This study offers the cases classification based on level of complexity, amount of time to complete, breadth of problem coverage, and method of presentation. For example, types of cases by level of complexity (reproductive training, partially-research, and creative-innovative cases) allow for taking into account the level of student training and the purpose of the training session. Such types of cases as mini-cases, medium-term, and long-term cases allow rational planning and use of study time.

While creating the case classification, the authors of this study determined the main requirements for the selection of cases: accessibility, scientificity, systematicity, contextuality and practical orientation, and methodological expediency. The authors’ choice of such a system of requirements is consistent with the views of Feagin et al. [8], Li and Yang [17], who offered some of these requirements.

5. Conclusions

The analysis of scientific papers confirmed the relevance of the study of the case classification, which is expedient to use while teaching methodical disciplines training would-be mathematics teachers. Based on the classification and survey of respondents, the authors of the study determined the classification characteristics of cases: the amount of time to complete, the way of presentation, the level of complexity, and the breadth of the problem covered.

It has been established that it makes sense to use mini-cases, medium-long cases, and long-term cases in the process of studying methodical disciplines according to the amount of time required to complete them. According to the method of presentation in the process of training would-be mathematics teachers, it is advisable to use cases in printed (handwritten) form, multimedia presentation of cases, and video cases. According to the level of complexity, it is appropriate to use reproductive training, partial research, and creative-innovative ones. Thematic and integrated cases should be used for the breadth of coverage of the problem. For each type of case, examples are provided that can be used while teaching methodological disciplines of would-be Mathematics teachers, and general requirements for case selection are offered. These requirements are based on taking into account the principles of accessibility, scientificity, contextuality, systematicity, methodological expediency, and practical orientation.

An important direction for future research is to study the effectiveness of the given case classification while methodical training would-be Mathematics teachers.

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The usage of stochastic matrices while learning the topic “Eigenvalues and eigenvectors of a matrix” in the course of Higher Mathematics

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Abstract. The article looks into teaching students mathematical modeling during the mastering of the topic “Eigenvalues and eigenvectors of a matrix” in the Linear Algebra. The modeling is based on the usage of matrices built based on Markov chains. The analysis of the researchers’ papers shows that the usage of matrices of this type can be implemented while teaching students of different university specialties. The analysis of the prerequisites for the involvement of stochastic matrices in the consideration of students has helped to determine additional concepts and theorems that should be considered while learning “Eigenvalues and eigenvectors of a matrix”. The theorem on the presence of stochastic vectors in a stochastic matrix can serve as a formula for systematizing problems that can present applications of eigenvalues and eigenvectors of the matrix in real-life situations. The results of the experiment conducted using the developed system of problems for students of different University specialties show the improvement of skills provided by mastering the topic “Eigenvalues and eigenvectors of a matrix”.

1. Introduction

The study of Linear Algebra is provided in the course of Higher Mathematics at the university. Matrices, their determinants, solving a system of linear equations, and modeling using them are considered while learning the course. Several hours are also devoted to the consideration of eigenvalues and eigenvectors. However, the practical application of these concepts is almost not traced, and therefore the importance of learning them remains unclear to students. Mathematical modeling using eigenvalues and eigenvectors based on the usage of stochastic models is also neglected.

Many scientists are interested in mathematical modeling and its involvement in teaching Mathematics. Thus, Kavanagh and Galluzzo study mathematical modeling as an iterative process that consists of several components. They believe that one of the most important issues for students during modeling is time management, that is, during this process, students can



easily get confused if teachers do not brainstorm with them and do not formulate the problem succinctly [1, 2]. In our opinion, indeed, mathematical modeling is a rather difficult process for students, but mathematical modeling itself will help motivate students to study Mathematics. One of the first models presented to students is a matrix, namely a stochastic matrix. In the course of mathematical modeling, a stochastic model is often built, which is a model of many processes in the surrounding world. Most stochastic processes are depicted in the form of Markov chains. Markov random processes, in particular Markov chains, as a mathematical model, are used to study processes in many branches of science, in particular in economics, ecology, sociology, technology, and industry [3–11].

Klumpenhouwer conducts research that presents an adapted mathematical framework for modeling transportation networks using Markov chains and presents a new tool that allows users to rapidly prototype and analyze stochastic networks using data or theoretical distributions [12].

Krenzler et al. develop algorithms for studying the modification of Jackson networks using Markov chains in a stochastic environment. The constructed algorithms respond to changes in the environment, the result of which is a clear calculation of the joint stationary distribution of the queue length vector and the environment [13]. Kenton views stochastic modeling as a form of financial modeling used to make investment decisions. Stochastic modeling is used in various industries around the world. The insurance industry, for example, relies heavily on stochastic modeling to predict what companies' balance sheets will look like at some point in the future. Some other sectors and fields depend on stochastic modeling, including stock investing, statistics, linguistics, biology, and quantum physics [14]. Brans studies Markov models as a stochastic variable system, and their use in business applications, forecasting, and machine learning [15]. Based on Markov chains, Zhang et al. model the process stochastically of diffusion and chemical reactions of chloride ions in concrete bridges, which will allow timely maintenance [16]. Bento considers the mathematical modeling of stochastic processes using a Markov chain. She describes the Markov model as a realistic tool for describing the world and creating long-term forecasts regarding some processes or systems [17].

From the listed studies, it can be seen that Markov chains have a fairly wide application in various spheres of life, so they require further research, which we consider based on eigenvalues and eigenvectors.

“Eigenvalues and eigenvectors of a matrix” is not a simple topic for students to understand. It is believed, that a properly and correctly composed system of problems on the topic will allow the student not only to practice the competencies, skills, and abilities to solve problems on the topic but also to demonstrate the application of the acquired knowledge in other branches of science and spheres of life, which will increase the motivation of students to study topics. So, having chosen the topic “Eigenvalues and eigenvectors of a matrix”, it compiled a system of problems for students of various specialties. Systematized problems were aimed at developing certain skills. The separation of these skills can be demonstrated using the following Problem 1.

Problem 1. Two companies, X and Y, provide telephone, Internet, and digital television and share a market of 5 million people. Company X is not very customer-friendly and loses 12% of its customers to Company Y every year. Not all of Company Y's customers are satisfied with their service and every year 3% of Company Y's customers switch to Company X. We want to investigate how the number of customers of both companies will change from sometimes. It is presented in table 1 the solving to the problem and highlighted the skills that the student needs for this.

Table 1: Solving Problem 1.

Skills needed to solve the problem	Steps of problem solving
1. The student knows what discrete-time Markov chains are and how they are formed	This is a special case of a Markov chain.
2. The student knows how to enter notation and create a system of equations that reflects the process described in the problem	The number of customers of company X in year n is denoted by x_n and the number of customers of company Y in year n by y_n . Then the sequences $\{x_n\}$ and $\{y_n\}$ satisfy the following system of equations: $x_{n+1} = 0.88x_n + 0.03y_n,$ $y_{n+1} = 0.12x_n + 0.97y_n.$
3. The student is able to rewrite the system of linear equations in matrix form	The system of equations is rewritten in matrix form $\forall n \in N : \begin{pmatrix} x_{n+1} \\ y_{n+1} \end{pmatrix} = \begin{pmatrix} 0.88 & 0.03 \\ 0.12 & 0.97 \end{pmatrix} \begin{pmatrix} x_n \\ y_n \end{pmatrix}$
4. The student knows how to recognize stochastic matrices, define them formally and knows which definitions and theorems of the topic "Eigenvalues and eigenvectors of a matrix" work with them	Based on the recursion, a mathematical model is obtained that shows the relationship between the number of customers in year n and the number of customers at the beginning (so-called initial conditions) $\forall n \in N : \begin{pmatrix} x_n \\ y_n \end{pmatrix} = \begin{pmatrix} 0.88 & 0.03 \\ 0.12 & 0.97 \end{pmatrix}^n \begin{pmatrix} x_0 \\ y_0 \end{pmatrix},$ with stochastic matrix $\begin{pmatrix} 0.88 & 0.03 \\ 0.12 & 0.97 \end{pmatrix}$ This switching matrix has some special characteristics: all its elements are non-negative, and the sum of the elements in each column is 1. Each element of this matrix represents the probability that a customer will be loyal to his operator or switch from it to another operator.
5. The student knows how to find the eigenvalues of the matrix	The eigenvalues of the matrix are found $\begin{pmatrix} 0.88 & 0.03 \\ 0.12 & 0.97 \end{pmatrix}$

Skills needed to solve the problem	Steps of problem solving
<p>6. The student knows the theorem on the presence of stochastic vectors of the stochastic matrix and knows how to work with it.</p> <p><i>Theorem.</i> If one takes $M \in R^{n \times n}$ as a stochastic matrix, where $m_{i,j} \geq 0$ for all $i, j \in \{1; \dots; n\}$. Then</p> <p>(a) there exists a unique stochastic vector v^* which is the corresponding eigenvector to the eigenvalue 1.</p> <p>(b) eigenvalues λ of the matrix M other than 1 satisfy $\lambda < 1$.</p> <p>(c) for all stochastic vectors v one has $\lim_{n \rightarrow \infty} M^n v = v^*$.</p>	<p>which is a stochastic matrix with only positive elements, and has eigenvalues 0.85 and 1, the latter as expected, and the former indeed satisfies $0.85 < 1$. Since the transition matrix has only positive elements, the stochastic vector existence theorem can be applied. A unique stochastic eigenvector $(x^*; y^*)$, corresponding to the eigenvalue 1 is determined. Direct calculation leads to the equation $0,12x^* = 0,03y^*$, so the vector $(1; 4)$ and its nonzero multiples are eigenvectors, corresponding to the eigenvalue 1. Of course, only the eigenvector</p> $(x^*; y^*) = \left(\frac{1}{5}; \frac{4}{5} \right)$ <p>is stochastic. When solving the system of equations, it is mentioned that the initial values $(x_0; y_0)$ satisfy $x_0 + y_0 = 1$. The item (c) of the theorem applies, i.e.</p>
<p>7. The student has skills to analyse the results obtained as a result of solving the model and come to conclusions</p>	<p>One comes to the same conclusion as before: regardless of the initial market shares $(x_0; y_0)$, Company Y will have four times as many customers as Company X or, equivalently, Company X will have a market share of 20%, and company Y will have a market share of 80%.</p>

After distinguishing the system of skills, it was expected to develop not only skills directly related to the mastery of the topic but also skills. This development will help to understand where the calculations of eigenvectors and eigenvalues of the matrix can be used.

So, the study aimed to develop a system of problems for learning the topic “Eigenvalues and eigenvectors of a matrix” to students of different university specialties. With the help of systematized problems, show students the usage of eigenvectors and eigenvalues in various branches of science and spheres of life. To conduct an experiment in which students of different university specialties will take part, to check the impact of the developed system of problems on the development of students’ skills.

2. Method

The research method was the systematization of problems to show students the usage of eigenvectors and eigenvalues in various fields of science and spheres of life. Before developing the problems, several related theoretical propositions were identified, which became the basis for their systematization and solution.

1. Definition of stochastic matrix and stochastic vector.

It is taken $M \in R^{n \times n}$ and $\nu = (\nu_1; \dots; \nu_n) \in R^n$.

If $m_{i,j} \geq 0 \forall i, j \in \{1; \dots; n\}$ and $\sum_{i=1}^n m_{i,j} = 1 \forall j \in \{1; \dots; n\}$ then the matrix M is called a stochastic matrix, which is sometimes also called a probability matrix or a Markov matrix.

If $\nu_i \geq 0 \forall i \in \{1; \dots; n\}$ and $\sum_{i=1}^n \nu_i = 1$, then the vector ν is called a stochastic vector, sometimes also called a probability vector.

2. The theorem on the product of a stochastic vector by a stochastic matrix. It is taken $M \in R^{n \times n}$ as a stochastic matrix, and $(\nu_1; \dots; \nu_n) \in R^n$ – a stochastic vector. Then the transposed $M\nu^t$ is also a stochastic vector.

Proof. With $m_{i,j} \geq 0 \forall i, j \in \{1; \dots; n\}$ and $\nu_i \geq 0 \forall i \in \{1; \dots; n\}$ the vector $M\nu^t$ has only non-negative elements. In addition,

$$\sum_{i=1}^n (M\nu^t)_i = \sum_{i=1}^n \left(\sum_{j=1}^n m_{ij} \nu_j \right) = \sum_{j=1}^n \left(\sum_{i=1}^n m_{ij} \right) \nu_j = \sum_{j=1}^n \nu_j = 1.$$

What had to be proved.

3. Definition of Markov chains

A Markov chain is a sequence of stochastic vectors (written as column vectors) $(\nu_0; \nu_1 = M\nu_0; \dots; \nu_n = M^n\nu_0; \dots)$ obtained by successive multiplication by the stochastic matrix M , starting from the stochastic vector ν_0 .

4. The theorem on the presence of 1 among the eigenvalues of the stochastic matrix.

It is taken $M \in R^{n \times n}$ as a stochastic matrix. Then 1 is an eigenvalue of M .

Proof. Consider the matrix $M - -E_n$. Since the sum of the elements of each column M is equal to 1, in the matrix $M - -E_n$ the sum of the elements of each column is equal to 0. As a result, if one sums all the rows of $M - -E_n$ it will be got a row with all elements equal to 0. This means that the rows of the matrix $M - -E_n$ are linearly dependent. Therefore, $\det(M - -E_n) = 0$ and 1 is an eigenvalue of M . What had to be proved.

5. The theorem on the presence of stochastic vectors in a stochastic matrix. It is taken

$M \in R^{n \times n}$ as a stochastic matrix, with $m_{i,j} \geq 0 \forall i, j \in \{1; \dots; n\}$. Then

(a) there exists a unique stochastic vector ν^* which is the corresponding eigenvector to the eigenvalue 1.

(b) eigenvalues λ of the matrix M other than 1 satisfy $|\lambda| < 1$.

(c) for all stochastic vectors ν we have $\lim_{n \rightarrow \infty} M^n \nu = \nu^*$.

The last theorem has become the main one while systematizing and solving problems. It is considered the system of problems that will allow students of different university specialties to demonstrate the application of eigenvalues and eigenvectors of the matrix in practice (table 2). During the systematization of problems, the peculiarities of the chosen specialties were taken into account.

Table 2: Problems' system.

Code specialties	Problems
073 Management; 075 Marketing; 076 Entrepreneurship, Trade and Exchange Activity; 111 Mathematics; 113 Applied Mathematics; 014 Secondary Education (Mathematics)	1,000 employees are constantly active at the big festival. To ensure that these employees remain motivated, they are regularly involved in other activities. There are three types of activities, namely security, sales, and cleaning. From past experience, the organizer knows exactly how many employees should perform each type of activity at any given time. Therefore, the organization uses the following table 2.1 every half hour to determine how employees switch to another activity, because this way the requirements are met in the best way

Code specialties	Problems																
	<p style="text-align: center;">Table 2.1: Employees' switching to another activity</p> <table border="1" style="margin-left: auto; margin-right: auto;"> <tr> <td style="text-align: center;">from to</td> <td style="text-align: center;">security</td> <td style="text-align: center;">sales</td> <td style="text-align: center;">cleaning</td> </tr> <tr> <td style="text-align: center;">security</td> <td style="text-align: center;">0.4</td> <td style="text-align: center;">0.3</td> <td style="text-align: center;">0.2</td> </tr> <tr> <td style="text-align: center;">sales</td> <td style="text-align: center;">0.1</td> <td style="text-align: center;">0.4</td> <td style="text-align: center;">0.1</td> </tr> <tr> <td style="text-align: center;">cleaning</td> <td style="text-align: center;">0.5</td> <td style="text-align: center;">0.3</td> <td style="text-align: center;">0.7</td> </tr> </table> <p>The numbers in the first column mean that every half hour the security workers will switch to another activity as follows: 4 out of 10 will continue to security, 1 out of 10 will switch to sales and 5 out of 10 will switch to cleaning. At the start of the festival, 500 employees will be engaged in security, 400 in sales, and 100 in cleaning.</p> <p>(a) Estimate how many employees will be involved in security after the festival is over for more than one hour.</p> <p>(b) Calculate how many workers will be removed in the long run. This number can be approximated by assuming that the festival lasts indefinitely</p>	from to	security	sales	cleaning	security	0.4	0.3	0.2	sales	0.1	0.4	0.1	cleaning	0.5	0.3	0.7
from to	security	sales	cleaning														
security	0.4	0.3	0.2														
sales	0.1	0.4	0.1														
cleaning	0.5	0.3	0.7														
<p>091 Biology; 203 Horticulture and 206 Viticulture; 206 Horticulture; 111 Mathematics; 113 Applied Mathe- matics; 014 Sec- ondary Education (Mathematics)</p>	<p>The color of the dragon flower is a property determined by two genes, which we denote as A and a. A plant with genotype AA is red, a plant with genotype Aa is pink, and a plant with genotype aa is white. A plant will pass to its offspring if it has two genes; we assume that both genes have the same probability of transmission.</p> <p>A florist has a large population of dragon flowers with a red colour (genotype AA), which are called generation 0 plants. The florist fertilizes each of these plants with pollen from plants with a pink colour (genotype Aa) from another population. Each plant has one new plant as an offspring, and we call these new plants generation 1 plants.</p> <p>Since the pollen used for fertilization is probably one half containing the A gene and half is likely to be a a gene, while the generation 1 plants have already received the A gene from the generation 0 plant, half of the generation 1 plants are red and the other half is pink.</p> <p>The florist repeats this process: plants of a certain generation are fertilized with pollen from a plant with a pink colour so that each plant has a new plant as the offspring of the next generation. It is denoted by x_n, y_n and z_n, respectively, the fractions of plants with red, pink, and white colour in generation n. That is, $x_0 = 1, y_0 = 0, z_0 = 0$ and $x_1 = 0.5, y_1 = 0.5, z_1 = 0$.</p> <p>(a) Calculate x_2, y_2 and z_2.</p> <p>(b) Express x_{n+1}, y_{n+1} and z_{n+1} in terms of x_n, y_n and z_n for $n \in N$.</p> <p>(c) Compute the limit of the sequences x_n, y_n and z_n. What is the meaning of these limit? [18]</p>																

Code specialties	Problems
101 Ecology; 103 Earth Sciences; 201 Agronomy; 111 Mathematics; 113 Applied Mathematics; 014 Secondary Education (Mathematics)	<p>An ecosystem that contains 4 (sources) of atmospheric pollution is being studied: $\omega_1, \omega_2, \omega_3$ and ω_4. For one specific period of time, these points undergo the changes described below. In point ω_1 as a source of pollution, 0.1 of the initial pollution remains there, 0.18 of it goes to point ω_2, 0.2 to point ω_3, 0.3 to point ω_4, and 0.22 of all pollution is dispersed. Similarly, in the same period of time, 0.11 of the initial pollution remains in point ω_2, 0.29 of it moves to point ω_1, 0.15 to point ω_3, 0.1 to point ω_4, and 0.46 is dispersed. At point ω_3, the picture is like: 0.1 pollution remains here, 0.12 goes to ω_1, 0.32 to ω_2 and 0.2 to ω_4, and 0.26 is dispersed in the atmosphere. At point ω_4, 0.05 of pollution remains, 0.23 of it goes to ω_1, 0.19 to ω_2, 0.13 to ω_3, and 0.4 is dispersed in the atmosphere. Find the vector f when it is known that the value of t is large enough, and also the vector of pollution restrictions is given $q = (10; 10; 10; 10)$ [18].</p>
51 Economics; 101 Ecology; 103 Earth Sciences; 201 Agronomy; 111 Mathematics; 113 Applied Mathematics; 014 Secondary Education (Mathematics)	<p>Statistical processing of observations of the meteorological service, carried out in the summer for a certain city of Ukraine, gave the following results:</p> <ul style="list-style-type: none"> • if a certain day was warm and cloudless, then the probability that the same weather will remain the next day is equal to 0.6; the probability that it will change to windy weather is 0.25, and to rainy weather – 0.15; • when the weather was windy, the probability that it will remain the same the next day is 0.32, and the probability that it will change to quiet sunny weather is 0.46, and to rainy weather – 0.22; • and if the weather was rainy, the probability that it will not change the next day is 0.26, and the probability that it will change to windy or sunny calm weather is 0.29 and 0.45, respectively. <p>Determine what the weather will be like in the summer of a certain city of Ukraine most often [18].</p>
112 Statistics; 111 Mathematics; 113 Applied Mathematics; 011 Educational, Pedagogical Sciences; 014 Secondary Education (Mathematics)	<p>According to the results of processing statistical information about the educational process of some University of Ukraine, the following data about its average student were obtained:</p> <ul style="list-style-type: none"> • a 1st-year student with a probability of 0.1 stops his studies due to failure, with a probability of 0.25 remains a freshman for another year and with a probability of 0.65 transfers to the 2nd year; • a 2nd-year student with a probability of 0.15 drops out due to failure, with a probability of 0.3 repeats the 2nd year, with a probability of 0.55 goes to the 3rd year; • a 3rd-year student drops out with a probability of 0.22, becomes a sophomore with a probability of 0.31, transfers to the 4th year with a probability of 0.57; • a 4th-year student drops out with a probability of 0.12, becomes a second-year student with a probability of 0.2, and transfers to the 5th year with a probability of 0.68; • a 5th-year student drops out with a probability of 0.05, becomes a sophomore with a probability of 0.15, presents a thesis with a probability of 0.8 and leaves the University as a certified specialist.

Code specialties	Problems																
	Determine what percentage of students leave the University as a certified specialist [18].																
141 Power Engineering, Electrical Engineering and Electromechanics; 112 Statistics; 242 Tourism; 111 Mathematics; 113 Applied Mathematics; 014 Secondary Education (Mathematics)	<p>Electricity consumption in summer is closely related to air temperature. Therefore, when planning the production and use of electricity for each day, the power company that supplies the city’s population with electricity must take into account the probability of hot, moderate or cool weather. Long-term observations have shown that the probability that the weather will be hot, moderate or cool tomorrow depends only on the weather today – hot, moderate or cool (see table 2.2).</p> <p style="text-align: center;">Table 2.2: Employees’ switching to another activity</p> <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th></th> <th>Hot</th> <th>Moderate</th> <th>Cool</th> </tr> </thead> <tbody> <tr> <th>Hot</th> <td>60%</td> <td>30%</td> <td>20%</td> </tr> <tr> <th>Moderate</th> <td>30%</td> <td>50%</td> <td>40%</td> </tr> <tr> <th>Cool</th> <td>10%</td> <td>20%</td> <td>40%</td> </tr> </tbody> </table> <p>(a) What will the weather be like on Thursday if it is moderate on Tuesday? (b) What is the prevailing summer weather in this region and by what percentage? [18]</p>		Hot	Moderate	Cool	Hot	60%	30%	20%	Moderate	30%	50%	40%	Cool	10%	20%	40%
	Hot	Moderate	Cool														
Hot	60%	30%	20%														
Moderate	30%	50%	40%														
Cool	10%	20%	40%														
275 Transport Technologies; 112 Statistics; 242 Tourism; 111 Mathematics; 051 Economics; 113 Applied Mathematics; 014 Secondary Education (Mathematics)	<p>The purpose of the study was to find out what type of transport (trolleybus, bus, subway) the average resident of the capital uses to commute. It was found that when he/she went to work by bus on a certain day of the working week, the probability that he/she would also use the bus the next day was 0.6, and the probability that he/she would change the bus to a trolleybus or subway is 0, respectively .35 and 0.05. If he/she first travelled by trolleybus, the probability that he/she would not change the mode of transport the next day is 0.7, and the probability that he/she would change the mode of transport to the bus or subway is 0.25, and 0.05, respectively. Finally, if the resident first used the subway, the probability that the next day would be the same mode of transport is 0.8, and the probability of changing to a bus or trolleybus is 0.05 and 0.15, respectively.</p> <p>Make a one-step transition matrix of a system that has three states corresponding to three types of urban transport used by a resident, and determine the probability that he/she would use the bus on Wednesday and Friday if on Monday he/she travelled by subway (a five-day work week). What type of transport will the average resident of the capital use to commute most often in the future [18]</p>																
111 Mathematics; 113 Applied Mathematics; 014 Secondary Education (Mathematics)	<p>In order not to be bored due to the measures against COVID-19, Alexander, Beth and Charles came up with a game. Each of them chooses an initial account. In each round of the game, each of them receives as the average of the other two players’ scores. For example: If they choose starting scores of 3, 193 and 59 respectively, then the scores change as follows (see table 2.3).</p>																

Code specialties	Problems																
	<p style="text-align: center;">Table 2.3: Score after rounds</p> <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th></th> <th style="text-align: center;">Alexander</th> <th style="text-align: center;">Beth</th> <th style="text-align: center;">Charles</th> </tr> </thead> <tbody> <tr> <td>Starting score</td> <td style="text-align: center;">60%</td> <td style="text-align: center;">30%</td> <td style="text-align: center;">20%</td> </tr> <tr> <td>Score after round 1</td> <td style="text-align: center;">30%</td> <td style="text-align: center;">50%</td> <td style="text-align: center;">40%</td> </tr> <tr> <td>The score after the 2nd round</td> <td style="text-align: center;">10%</td> <td style="text-align: center;">20%</td> <td style="text-align: center;">40%</td> </tr> </tbody> </table> <p>The winner is the player who has the most points after 999 rounds. (a) Express the score of each of the three players after round n in terms of the points after round $n - 1$. (Here n is an arbitrary integer greater than or equal to 1, and we denote by ‘scores after round 0’ the initial scores). (b) If Alexander and Beth choose their starting score and reveal it, what strategy do you recommend Charles use to win the game? Explain why. (c) What happens to the scores if they do not stop after 999 rounds, i.e., the game goes on forever?</p>		Alexander	Beth	Charles	Starting score	60%	30%	20%	Score after round 1	30%	50%	40%	The score after the 2nd round	10%	20%	40%
	Alexander	Beth	Charles														
Starting score	60%	30%	20%														
Score after round 1	30%	50%	40%														
The score after the 2nd round	10%	20%	40%														
075 Management; 111 Mathematics; 051 Economics; 113 Applied Mathematics; 014 Secondary Education (Mathematics)	<p>80,000 visitors are constantly present at the concert. They are divided into three stages, and the organization measures movements every fifteen minutes between these stages in percentages, as in the following table 2.4.</p> <p style="text-align: center;">Table 2.4: Movements every fifteen minutes between stages</p> <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th style="text-align: center;">from to</th> <th style="text-align: center;">stage A</th> <th style="text-align: center;">stage B</th> <th style="text-align: center;">stage C</th> </tr> </thead> <tbody> <tr> <td style="text-align: center;">stage A</td> <td style="text-align: center;">50%</td> <td style="text-align: center;">40%</td> <td style="text-align: center;">30%</td> </tr> <tr> <td style="text-align: center;">stage B</td> <td style="text-align: center;">30%</td> <td style="text-align: center;">30%</td> <td style="text-align: center;">30%</td> </tr> <tr> <td style="text-align: center;">stage C</td> <td style="text-align: center;">20%</td> <td style="text-align: center;">30%</td> <td style="text-align: center;">40%</td> </tr> </tbody> </table> <p>The percentages in the first column mean that every fifteen minutes the visitors to stage A are distributed as follows: 50% stay at stage A, 30% go to stage B, and 20% go to stage C. At the start of the concert, there are 40,000 people at Stage A, 20,000 at Stage B and 20,000 at Stage C. (a) How many visitors will there be at stage A after 30 minutes? (b) How many visitors will there be after k 15 minutes at stage B? (c) How many people are in attendance at the end of the concert at stage C?</p>	from to	stage A	stage B	stage C	stage A	50%	40%	30%	stage B	30%	30%	30%	stage C	20%	30%	40%
from to	stage A	stage B	stage C														
stage A	50%	40%	30%														
stage B	30%	30%	30%														
stage C	20%	30%	40%														
051 Economics; 292 International Economic Relations; 111 Mathematics; 113 Applied Mathematics; 014 Secondary Education (Mathematics)	<p>Economists study the economic condition of 150 countries and divide them into two groups: those in recession and those that are not in recession. If a country is in a recession, the probability that the country will still be in a recession next year is 70%. Countries that are not in recession have an 80% chance of still not being in recession in the next year. Currently, 50 out of 150 countries are in recession. How many countries do you think are in a long-term recession?</p>																

3. Results

To check the effectiveness of using the system of problems in which stochastic models are used in classes of Linear Algebra, an experiment was conducted. The base for experimenting

was Universities: National University of “Kyiv-Mohyla Academy” and Kryvyi Rih State Pedagogical University and students of majors: 073 Management; 075 Marketing; 076 Entrepreneurship, Trade and Exchange Activity; 113 Applied Mathematics; 014 Secondary Education (Mathematics).

The main tasks of the experiment were: the study of learning “Eigenvalues and eigenvectors of a matrix” by students of different majors; developing and implementing the system of problems that can demonstrate the usage of eigenvectors and eigenvalues of the matrix while constructing stochastic models; analysis of the experiment’s results.

The control group (CG) and the experimental group (EG) were formed at the beginning of the experiment to determine the level of students’ mathematical preparation after testing the first few topics of the Linear Algebra section in the Higher Mathematics course. After the end of the experiment, students were tested again. At the beginning and the end of the experiment, students of the control and experimental groups solved the same system of problems developed by the authors of this study.

The experiment lasted two weeks, during which the eigenvalues and eigenvectors of the matrix were studied in the course of the considered section of Higher Mathematics. 125 students took part in the experiment, of which 64 students were included in the control group and 61 students in the experimental group:

- the control group (CG) included students of majors 076 Entrepreneurship, Trade and Stock Exchange Activity; 113 Applied Mathematics; 014 Secondary education (Mathematics) from the National University of “Kyiv-Mohyla Academy” and Kryvyi Rih State Pedagogical University. Learning “Eigenvalues and eigenvectors of a matrix” in these groups was carried out with the usage of the standard problems;
- students who majored in 073 Management, 075 Marketing, 014 Secondary Education (Mathematics) from the National University of “Kyiv-Mochyla Academy” and Kryvyi Rih State Pedagogical University were involved in the experimental group. The experiment was carried out using the developed system of problems, in which modeling on stochastic models was considered using the eigenvalues and eigenvectors of the matrix.

At the beginning of the experiment, students in the control and experimental groups wrote the same test, dedicated to determinants, matrices, their properties, and solving systems of linear equations. The control was carried out to show the equivalence of the selected groups. The mode of test results for the experimental and control groups coincided. Then in the control group, the presentation of eigenvalues and vectors was carried out according to the traditional method, and in the experimental group, the developed system of problems was used.

The test, which was offered to students at the final stage of the experiment, contained three types of problems. The first type of problem is aimed at working out the steps of calculating the eigenvalues and eigenvectors of the matrix, namely, solving the equations given in the form of determinants and finding the fundamental system of solutions of an indeterminate homogeneous system of linear equations. This type of problem tests the skill to rewrite a system of linear equations in matrix form (Skill 1). The second type of problem is to find eigenvectors and eigenvalues of matrices of different order. These problems are aimed at testing students’ skills to calculate eigenvectors and eigenvalues of a matrix (Skill 2). The third type of problem includes tasks on the application of eigenvectors and eigenvalues of the matrix, namely, finding the canonical equation of the second-order line, as well as tasks on developing a linear exchange model (international trade model). This type of problem was given to test the skill to build mathematical models for a problem, as well as the skill to adapt the obtained results following the condition of the problem and the ability to come to a specific conclusion (Skill 3).

It is presented in the table 3 and the diagram (figure 1) the percentage of correctly completed problems of the first, second, and third types, that is, the level of formation of the corresponding

Table 3. The percentage of formation of the relevant skill in CG and EG.

	Skill 1	Skill 2	Skill 3
Percentage in KG	84.4	67.2	54.7
Percentage in EG	91.8	83.6	78.7

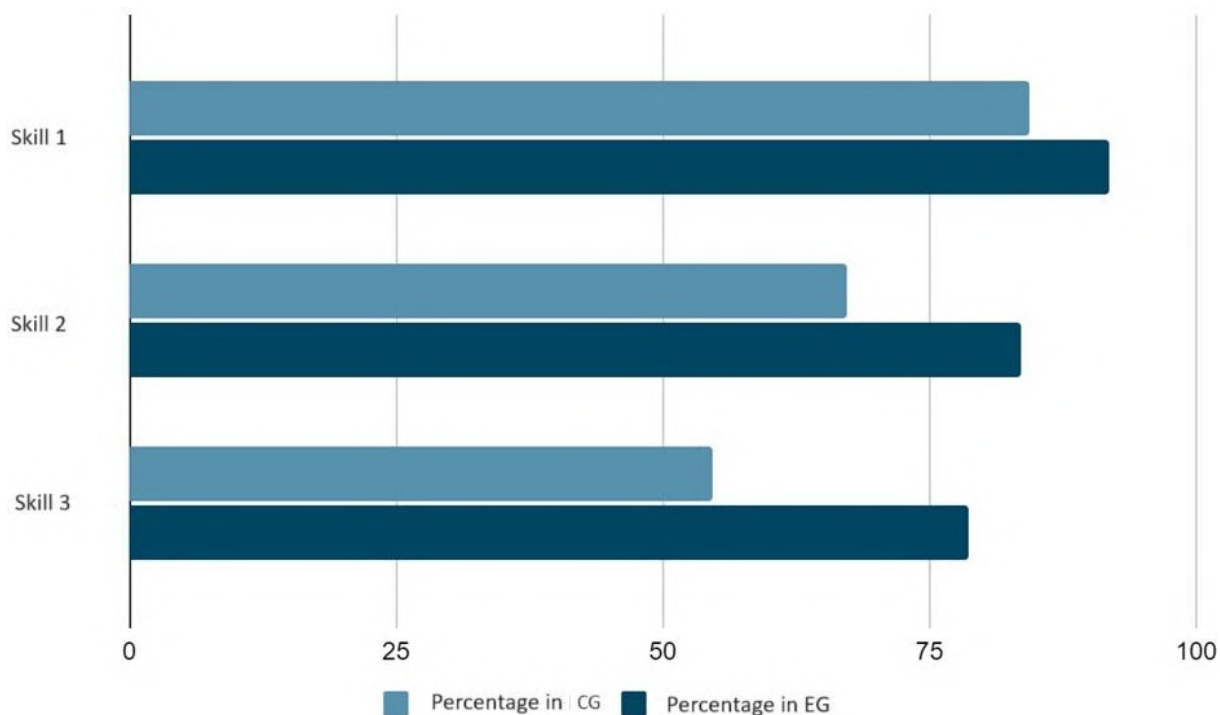


Figure 1. Results of the test at the final stage of the experiment

skill in each group.

It is clear from the table and diagram that the percentage of skills 1, 2, and 3 in the experimental group is higher than in the control group, for the first skill 7.4%, for the second skill – by 16.4%, and for the third skill – by 24%. It confirms the effectiveness of the problem system that was developed, in which modeling on stochastic models is considered using eigenvalues and eigenvectors of the matrix.

4. Discussion

One of the issues of linear algebra is the calculation of the eigenvector of a matrix associated with a known eigenvalue. This issue can be presented on realistic problems by replacing arbitrary matrices with stochastic ones and performing mathematical modeling on their basis. This approach, according to Vlasenko et al. [19], contributes to improving students’ understanding of the importance of calculating the eigenvector and the eigenvalue of the matrix. This opinion was taken into account, so the standard matrices were replaced by matrices based on Markov chains.

Markov chains are widely used in various scientific fields. Their involvement can be found in both natural and social sciences. These matrices are used to explain the problems of movement in time or space, respectively, the transition from one state to another [20]. This type of matrix can be seen during the description, analysis, forecasting, and development of various features,

such as migration, employment, and changes in urban systems and landscape [21–23]. So, we had a sufficient number of examples of their involvement to develop a system of problems that can be used while teaching the topic “Eigenvalues and eigenvectors of the matrix” to students given their major. Setting the conditions of the problems was carried out based on observing the stages of their solution to the conclusions of the theorem on the existence of stochastic vectors of the stochastic matrix $M \in R^{n \times n}$ where $m_{i,j} \geq 0 \forall i, j \in \{1; \dots ; n\}$.

Therefore, the theorem became a formula for the systematization of problems with which the students of the experimental group worked. Of course, the students of the same group were also familiarized with all the theoretical provisions that ensure the modeling and solving obtained formalized models. The results of the experiment confirmed the expediency of using the developed problem system for learning the topic “Eigenvalues and eigenvectors of the matrix”.

5. Conclusions

There is no doubt about the importance of teaching students mathematical modeling when learning Linear Algebra topics in the Higher Mathematics course. Learning the topic “Eigenvalues and eigenvectors of a matrix” is no exception. However, finding the eigenvalues and their corresponding eigenvectors of the matrix causes difficulties for students due to the lack of understanding of their use in real life. Such a misunderstanding can be eliminated through the usage of matrices built based on Markov chains.

Stochastic matrices have wide application in various scientific fields (data analysis, probability theory, statistics, mathematics, computer science, and population genetics) and life practice (migration, employment, changes in urban systems and landscape, etc.). Therefore, using matrices of this type can be demonstrated to students of different University specialties. Provided students consider stochastic matrices, which are also called probability matrices, Markov matrices, or substitution matrices, additional concepts and theorems should be presented to students while studying the topic “Eigenvalues and eigenvectors of a matrix”. Among them: the definition of a stochastic matrix and a stochastic vector, the theorem on the product of a stochastic vector by a stochastic matrix, the definition of Markov chains, the theorem on the presence of 1 among the eigenvalues of a stochastic matrix, the theorem on the presence of stochastic vectors in a stochastic matrix.

The last theorem can be used as a basis for the systematization of problems that present applications of eigenvalues and eigenvectors of a matrix in real-life situations. This is explained by the fact that the stages of solving such problems must be carried out by observing the conditions and conclusions of this theorem. The usage of the developed system of problems and presentation of the theoretical foundations of its involvement while studying the topic “Eigenvalues and eigenvectors of the matrix” does not require a significant increase in hours. The results of the experiment show that students who work with the recommended system of problems demonstrate better results, which course to the improvement of skills ensuring mastery of the topic.

6. CRediT author statement

- *K. V. Vlasenko*: Conceptualization, Supervision, Project administration
- *T. S. Armash*: Methodology, Investigation, Writing – Original Draft, Writing - Review & Editing
- *A. A. Kostikov*: Formal analysis, Data Curation, Visualization
- *I V Lovianova*: Investigation, Resources
- *M V Moiseienko*: Writing – Review & Editing, Validation

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The poster features a dark blue background with a green circular graphic on the left containing the text 'ECS UNITED' and a stylized 'E' with three vertical bars. The ECS logo and name are in the top right, with the tagline 'Advancing solid state & electrochemical science & technology'. The meeting details are in the center right, and a green circle in the bottom right contains the abstract deadline.

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Structural-mathematical thinking and its development in teaching Mathematics

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Abstract. The paper highlights the content and components of structural-mathematical thinking, substantiates its classification basis and establishes typological characteristics. In the conceptual-categorical section of the present study, structural-mathematical thinking is introduced as a form of theoretical thinking that embodies the specifics of mathematical comprehension of reality. The content as well as structural and functional characteristics of the phenomenon under study represent the content and components of the mathematical structure. Hence, the adherence to the deductive nature of Mathematics was ensured in the study, also emphasizing the phenomenological characteristic of structural-mathematical thinking regarded as the ability to reflect reality in accordance with the content components of the mathematical structure. Taking into account the theoretical advances, using the system approach and the modeling method, a model of developmental-conceptual teaching of Mathematics was elaborated. By considering the theoretical advancements and applying both a systemic approach and modeling method, a model for instructing Mathematics in a developmental-conceptual approach was elaborated, which represents a problem-based approach and develops students' structural-mathematical thinking. The crux of teaching Mathematics through a developmental and conceptual approach lies in creating a framework that addresses the three-fold challenge of problem-solving \longleftrightarrow competency-building \longleftrightarrow problem-solving proficiency. Taking into account the addressed issue, the paper elicits the outcomes of a pilot study how structural-mathematical thinking is manifested by the would-be teachers of Mathematics. Furthermore, the efficacy of the authors' approach to its enhancement is experimentally validated.

1. Introduction

The outcomes of the most recent external independent evaluation, along with those of the nationwide multi-disciplinary exam, indicate an urgent need for reconsidering scientific of mathematics education in Ukraine, rethinking the methodological principles, methods and pedagogical techniques. The development vector adopted at the national level, aimed at fostering competence-building of mathematical education, involves the contemporary study of complex mental processes, among which structural-mathematical thinking is distinguished as an internal characteristic of mathematical competence, as an immanent attribute of its personal and psychological dimension. The identification of structural-mathematical thinking as part of the internal dimension of mathematical competence determines the urgency of developing the content and procedural components for the methodology of competence-based teaching of Mathematics. Thus far, the educational practice has been firmly established, whereby the methodology of competence-based Mathematics education is supplanted by the



traditional approach to fostering mathematical knowledge and skills. The problem of developing students' structural-mathematical thinking is in no way connected with the implementation of the competence-based approach. The existing contradictions are caused by the lack of research in which the problem of the developing structural-mathematical thinking of the would-be educators the analysis delves into the principles pertaining to the duality of mathematical proficiency (its external and internal manifestations) as well as the theory of personal and developmental study of Mathematics. Furthermore, there exists a profound internal inconsistency between the substance of the field and its pedagogy: on the one hand, the deductive content of Mathematics, abstract mathematical structures, universal methods of mathematical research, which form theoretical generalizations and primarily facilitate theoretical (structural-mathematical) thinking, and on the other hand – the logic of educational cognition, the associative-reflective theory of learning, the established methodology of teaching Mathematics, which provide for the dominance of empirical generalizations and the actualization of empirical thinking, the leveling of structural-mathematical thinking and the formation of specific mathematical skills.

The problematic field of research includes the issues of content, structure, typology of students' structural-mathematical thinking, as well as substantiation and elaboration of the relevant methodology.

2. Literature review

The examination of methodological literary sources reveals that modern pedagogical research is primarily concerned with the development of individual indicators pertaining to the personal and psychological dimensions of mathematical competence [1, 2]. The scholars are focusing on a range of questions within this problem field, including:

- development of students' creative thinking in learning elementary Mathematics (the case study of an online course) [3];
- enhancement of mathematical concepts among students in general secondary education establishments while tackling geometry problems, contingent upon their individual cognitive learning style [4];
- updating the high level of mathematical abilities of secondary school students by means of reflexive abstraction (the case study of quadratic equations) [5];
- development of mathematical logical thinking of students, which takes into account the specifics of agricultural regions [6];
- development of logical thinking of high school students in the conditions of implementing a problem-based approach to teaching Mathematics [7];
- fostering the creativity of the would-be teachers' mathematical reasoning in the process of solving problems, which entails enhancing the proficiency of working memory [8];
- the impact of mathematical content on the enduring cognitive development of the young generation [9];
- correlating the structural elements of mathematical capabilities with measurements of students' external manifestation of mathematical competence in education, development, and experimental verification of the methodology for developmental Mathematics teaching [10];
- phenomenological characteristics of clip thinking in the conditions of educational and cognitive activity of students of natural science as well as physical-mathematical education profiles [11].

The current article addresses the internal manifestations of mathematical competence, specifically its personal-psychological dimension. One of the pivotal attributes in this realm is structural-mathematical thinking.

The purpose of the work is to reveal the content, structure, and typological characteristics of students' structural-mathematical thinking, to elaborate and scientifically substantiate a model of developmental-conceptual teaching of Mathematics, to verify experimentally the effectiveness of the developed methodology.

3. Methods

The pursuit of the set goal necessitates implementation of the following research methods: theoretical and systematic analysis (regarding the content, structure, and typological characteristics of structural-mathematical thinking, highlighting its place in the personal-psychological dimension of mathematical competence, as well as substantiating the theoretical foundations of the said methodology). Accordingly, in the course of the study additional methods were utilized, in particular abstraction and modeling (when building a model of personal and developmental teaching of Mathematics), ranking (when establishing the hierarchy of content-theoretical actions during structural-mathematical thinking, consequently determining the stages of learning Mathematics), statistical method (during a pilot study and experimental verification of the methodology), content generalization (in the presentation results and formulation of research conclusions).

3.1. The pilot study

The pilot study involved diagnosing the cognitive orientations of the would-be teachers of Mathematics. Drawing on its results, it was established which vectors prevail in the process of solving mathematical problems: theoretical or empirical. The study adopted the theoretical stance that the mode of students' mathematical learning is determined by the would-be teachers' cognitive orientations which encompass either theoretical or empirical vector. The dominant theoretical orientations serve as a factor in the development of students' structural-mathematical thinking, it is extrapolated to the personal dimension of professional readiness to implement the methodology of personal-developmental teaching of Mathematics. However, the use of empirical cognitive guidelines not only impedes this process but also hinders the acquisition of a novel (innovative) approach to teaching Mathematics, which aims to foster structural-mathematical thinking.

During the pilot study, a survey of first-year students was conducted, with 156 respondents participating. The objective was to rank in ascending order the factors deemed significant in solving mathematical problems, which entailed as follows: *devising a strategy (method) to solve the problem; identifying a method for tackling typical problems; providing an answer that addresses the question posed in the problem statement; and executing calculations accurately without errors.*

The significance of the factor was determined by calculating its coefficient using the following formula:

$$p_i = \sum_{k=1}^4 \frac{x_k k}{4n},$$

where p_i is the coefficient of significance of one of the four factors ($i = 1, 2, 3, 4$); n – the number of students who participated in the survey; x_k – the number of students who put the i -factor in k place. In the above formula, the coefficient of significance of the factor can vary from 0.25 to 1.

The results of the calculations allowed arriving at the conclusion that of paramount concern for first-year students is to find a strategy to tackle a problem, and hereafter identify a strategy (method) of tackling other typical problems (figure 1).

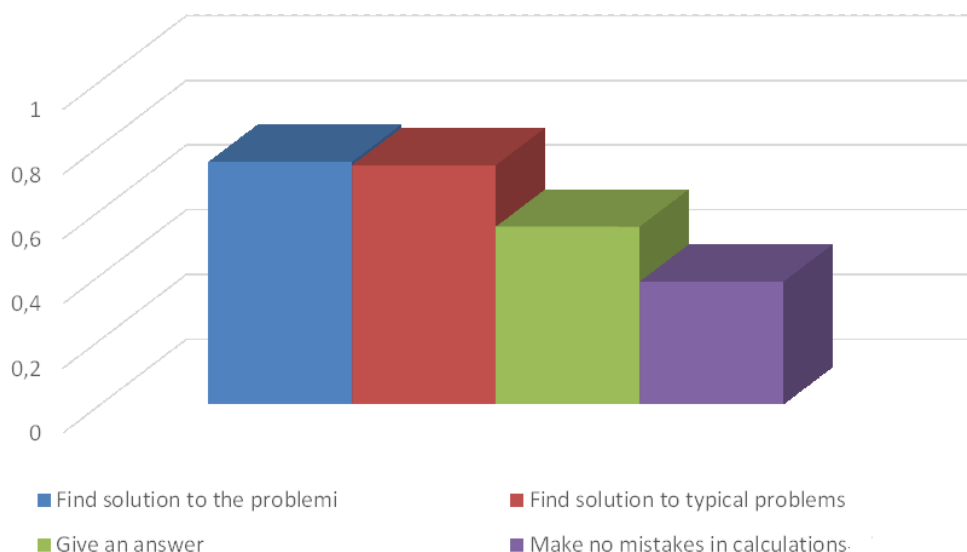


Figure 1. Cognitive orientations of the freshmen (significance coefficient).

In view of the above, the heuristic-theoretical cognitive orientations of first-year students can be distinguished, while also acknowledging the impact of empirical factors. The pilot experiment revealed that it is feasible to differentiate four categories of cognitive orientations among the would-be teachers of Mathematics:

- the first type is theoretical (T), characterized by a cognitive focus on finding a way to solve a whole type of problems;
- the second type is heuristic (HE), aimed at finding a strategy to solve the problem;
- the third type is practical (P), characterized by a pragmatic focus on the result (formulation of the answer to the question in the statement thereto);
- the fourth type is empirical (EM), in which the correctness of calculations is a cognitive point of reference.

Analysis of statistical data led to the conclusion that each of the abovementioned types can be divided into subtypes depending on which of the factors follows the leading one. Thus, the following subtypes within the theoretical type are singled out: theoretical-heuristic (THE), which makes up 72% of all theorists; theoretical and practical (TP) – 20%; theoretical-empirical (TEM) – 8%. The heuristic type also includes all possible subtypes: heuristic-practical (HEP) – 47%; heuristic-theoretical (HET) – 33%, heuristic-empirical (HEEM) – 20%.

The practical type is characterized by the following combinations: practical-theoretical (PT) – 50%, practical-heuristic (PHE) – 30%, practical-empirical (PEM) – 20%. Experimental data confirmed our hypothesis that the empirical-theoretical subtype is unlikely, and proved the existence of empirical-practical (EMP) and empirical-heuristic (EMEV) subtypes in approximately equal percentages.

So, the results of the pilot study proved the relevance of the problem raised in the research, the need to probe deeper into the structural-mathematical variety of theoretical thinking, as well as the need for methodological examination of the elaborated theory.

3.2. Ethical considerations

This study was conducted in accordance with the ethical standards for research involving human subjects. The research protocol was reviewed and approved by the Scientific Ethics Committee

of Zhytomyr Polytechnic State University (Protocol No. 2022-15).

Informed consent was obtained from all participants prior to their involvement in the study. The participants were informed about the purpose, procedures, and duration of the study, as well as their rights to confidentiality, anonymity, and voluntary withdrawal from the study at any time without consequences. The collected data were stored securely and used solely for the purposes of this research. The study adhered to the principles of beneficence, non-maleficence, and respect for participants' autonomy throughout the research process.

3.3. Theoretical substantiation of the research problem. Methodology of developmental-conceptual teaching of Mathematics

Theoretical thinking is a fundamental cognitive process that enables individuals to reflect on objective reality, identify patterns in the formation and development of knowledge objects, and formulate scientific concepts – genetically derived “cells” within the established epistemological framework. The foundation of theoretical thinking lies in content-theoretical actions such as analysis, abstraction, generalization, planning, and reflection.

Drawing upon analysis and abstraction, the elaborated model allows the cognitive operation of mentally transferring the object of knowledge to conditions outside its actual existence that ensures comprehensive investigation into its manifestations, connections, and relations. With that in mind, modeling as an indirect, mediated research method plays a fundamental role in the development of theoretical thinking, in establishing the leading role of theoretical knowledge in educational process. In further cognitive activity, the mental operations are carried out in accordance with the law of reflection and thinking, in particular the descent from the abstract to the concrete. Given the specifics of mathematics as a deductive science, such convergence is most fully realized in the axiomatic method, as well as in the process of problem solving.

Generalization as a thinking action enables establishing the relationship between the universal and the particular. One form of this approach, namely the content generalization, reveals the essence of things by analyzing their developmental patterns. Thus, conducting a substantive generalization means identifying regularities, linking individual phenomena to an overarching whole, and substantiating laws governing its formation. Accordingly, in the teaching of Mathematics, there should be not only definitions of concepts, but also those tasks that reveal their origin.

Planning is a component in the structure of theoretical thinking that provides a predetermined order of actions to achieve a goal. Content planning allows predicting the result, carrying out its preliminary analysis, avoiding the use of the trial and error method. In this light, the content planning (as the construction of a system of possible actions) is closely related to modeling, i.e. the creation of a mental model (structure) of a solution method as one of the forms of abstraction. The ability to make an indicative plan of action, to the content planning in the process of solving problems is a characteristic feature of a subject of educational activity with a developed theoretical type of thinking.

In the structure of theoretical thinking, a pivotal place is occupied by reflection (from the Latin *reflexio* “the process of self-knowledge by the subject of internal mental acts and states”). It encompasses the following skills and personal characteristics:

- perform self-analysis, self-control, self-correction and self-evaluation of the learning process;
- put forward hypotheses, verify or refute them;
- consider one's own actions and those of the members within the reference group;
- pose questions and independently find answers to them;
- elucidate an explanation of the need for novel approaches and methods;
- be critical of one's views and the views of interlocutors;

- find ways and methods of solving problems independently;
- engage in discussion in order to uphold one's viewpoint;
- reject conventional approaches to preconceived knowledge and ways of thinking.

The above type of theoretical thinking is called structural-mathematical, which ensures the discovery of regularities in the formation and development of objects of mathematical knowledge and draws upon the concept of "mathematical structure". The cognitive activity in question operates according to the following logical framework:

1. The nomenclature of theoretical entities deemed undefined is listed.
2. The basic relations are enumerated, in which fundamental concepts can be located and which are considered original (undefined, primitive).
3. Axioms are formulated, i.e. statements that are accepted without additional proof. Axioms expound major connections between fundamental concepts or assert the presence of certain fundamental concepts.
4. Each concept that occurs in a mathematical theory is strictly defined (if it is not known from other theories and does not belong to the fundamental concepts).
5. Each statement (theorem) that is not an axiom is rigorously proved. The proof is carried out by logical reasoning (according to the laws of logic) using accepted axioms and previously proven statements.
6. Applying the principle of moving from abstract to concrete, the theory is implemented and subsequent issues are resolved.
7. Reflection of mathematical knowledge is ensured, namely self-analysis, self-control, self-correction and self-assessment are carried out.

The introduction of such a logical scheme in the process of teaching Mathematics involves the application of structural-mathematical analysis of educational material as a content-theoretical action and a type of system analysis. According to the activity approach, it includes operations that ensure as follows:

- 1) justification of the theoretical and methodological foundations of the educational material (prominent mathematical concept, approaches to mathematical understanding and investigation);
- 2) clarification of basic mathematical concepts, relations and their features (axioms) according to the concept of mathematical structure;
- 3) identification of the network configuration comprising the signifying constructs and interrelationships, clarification of the methods of their introduction (definition);
- 4) selection of main theorems (signs, properties, criteria), justifications of their structure, strategies and methods of proof;
- 5) strict mathematical justification of performed transformations (algebraic, transcendental, geometric);
- 6) outlining the major types of problems, their structure, techniques, ways and methods of solving;
- 7) reflection of learning Mathematics (self-analysis, self-control, self-correction and self-assessment).

In view of the Cartesian interpretation of the three-dimensional structure in terms of the internal manifestation of mathematical competence, structural-mathematical thinking is

combined with memory of mathematical material, experience in mathematical activities, self-awareness ("I-concept" in mathematical activity) and mathematical abilities (figure 2). Thus, in such a way the comprehensive subsystem constitutes a personality and psychological dimension of mathematical competence.

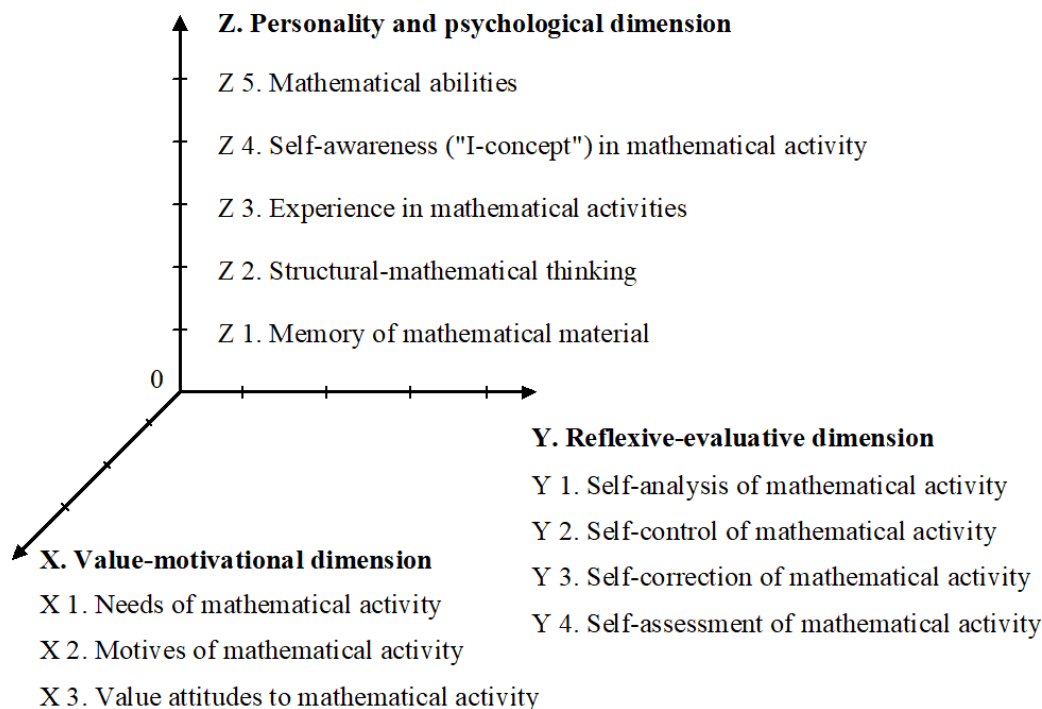


Figure 2. Three-dimensional structure of the internal manifestation of mathematical competence.

The current study presents the delineated actions based on content theory as those that serve to be the foundation for classification of structural-mathematical thinking. The following types thereof are distinguished: analytical, abstracting, generalizing, planning and reflective.

The analytical type characterizes structural-mathematical thinking, in which a structural-mathematical analysis is carefully performed as regards the educational material of both theoretical and problem components.

The abstracting type outlines structural-mathematical thinking, which is characterized by distraction from properties that are insignificant from the point of view of Mathematics and focusing attention on essential ones. An indispensable attribute thereof is mathematical modeling of problem situations.

The generalizing type represents structural-mathematical thinking, which provides content generalization of mathematical material, mastery of the Mathematics methodology, as well as a mental "grasp" of a typical formal structure (solution algorithm) based on one particular case.

The planning type highlights structural-mathematical thinking, the essential characteristic of which is the content planning of the problem-solving process, drawing up algorithmic and heuristic prescriptions, forming a prospective action plan in teaching Mathematics.

The reflective type of structural-mathematical thinking is characterized by the dominant role of reflection in teaching Mathematics, self-cognition of the subject of educational-mathematical activity, cognitive orientation to perceiving mathematical material.

The examination of theoretical foundations regarding the problem raised in the study involves

the establishment of psychological and pedagogical conditions for the development of structural-mathematical thinking.

First, the organization of their educational and mathematical activities according to the third type of education is attributed to the psychological and pedagogical prerequisites for the development of such thinking in students. In terms of forming the operational basis of actions, the psychological theory distinguishes between three types of training, namely [12]:

- 1) the instruction according to the set pattern, without provided guidelines on how to perform a certain action;
- 2) the instruction according to a ready-made algorithm, when all guidelines are provided regarding the task performance;
- 3) the instruction through the advanced content analysis, the result of which is elaborating a course of action, developing an algorithm for solving typical problems.

On the one hand, the instruction according to the third type of shaping the mental actions is presented as a process of educational activity. However, on the other hand, it actualizes structural-mathematical thinking, in particular its varieties, since it involves the performance of content-theoretical actions such as analysis, abstraction, generalization, planning and reflection. Rejection of the ready-made algorithm and the specified sample, activation of the student activity in the process of mathematical cognition serve as the factors that ensure the development of students' structural and mathematical thinking.

Second, the article addresses the introduction in Mathematics in accordance with the basic provisions of the theory of the step-by-step formation of mental actions and methods of mental activity as psychological and pedagogical conditions. In this light, the development of structural-mathematical thinking is connected with learning that is an integral feature of the learner's personality reflecting his ability to master educational and mathematical activities. According to this theory, the development of structural-mathematical thinking involves mastering the orientations of activity and methods of mental actions for the purpose of their planning and implementation. The instruction is conducted in the following stages [12]:

- 1) creation of motivation (engagement in the process of cognitive activity);
- 2) distinguishing the scheme of the prospective actions (identifying the sequence of executive and control operations included in the action);
- 3) elaboration of action in material or materialized form (graphical transformation of objects in which structural components are presented in the form of signs and symbols);
- 4) speech without relying on materialized means (all operations included in the action are learned in language form);
- 5) elaboration of an action in the inner language (thoughts), which serves to transfer the action into the mental plane;
- 6) transition of action into inner language, and inner language into thought (action becomes automatic).

It is worthy of note that structural-mathematical thinking cannot be transferred in a ready-made form, it is formed and developed in the course of the mental educational and mathematical activity of the subject.

Third, the place of structural-mathematical thinking in a complex system formation, which is mathematical competence, determines the attribution to the psychological-pedagogical conditions of its development, the formation of the principal indicators of each of the six dimensions [10]:

- in the value-motivational dimension of mathematical competence – the formed needs of mathematical activity;
- in the reflective-evaluative dimension – the action is formed to perform self-analysis of mathematical activity;
- in the personal-psychological dimension of mathematical competence – the memory for mathematical material is sufficiently developed;
- in the content-theoretical dimension – the basic mathematical concepts (relationships) are developed;
- in the procedural-active dimension of mathematical competence – logical-mathematical operations are performed;
- in the referential-communicative dimension – oral mathematical speech is sufficiently developed.

Fourth, the development of structural-mathematical thinking involves the establishment of actual mathematical development zones in students as well as the creation of zones of their nearest mathematical development. Students’ actual mathematical development zone is determined by independent educational achievements in Mathematics. The zone of immediate mathematical development is a component of Mathematics instruction in which, firstly, based on the results of joint activities, a degree of student independence is established in mastering a method of action in the process of solving a new type of problem. Furthermore, an expedient group (collectively distributed) is organized for educational and mathematical activity for mastering new knowledge and skills. Next, the phenomenological characteristic of such training is internalization, as a result of which the student solves a certain type of problem independently, and his individual psychological qualities have a higher level of development. In accordance with the task system of students’ educational and mathematical activity, four zones of immediate mathematical development are distinguished: basic, educational, educational-theoretical and educational-research.

Fifth, the research introduces a problem-based approach to the development of structural-mathematical thinking. It provides a set of methods of planning, organization, development and diagnosis of educational and mathematical activity of students, aimed at the development of phenomenological characteristics (content-theoretical actions) and varieties of structural and mathematical thinking. Accordingly, the said approach addresses a system of tasks.

The typology of mathematical problems based on the mathematical modeling method (applicable or inapplicable) is presented in figure 3 as follows.

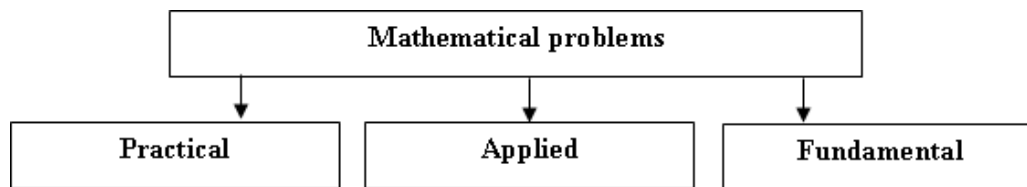


Figure 3. The typology of mathematical problems.

Besides, for the purposes of the current study, the generally recognized classification basis of problems are used, namely the content of the task requirement. The mathematical problems of the following types are distinguished: calculation, construction, proof problems, and research problems.

Separately, competency mathematical problems are singled out. Competency problem in Mathematics is a type of reflective problem, in the process and according to the results of solving

which the zones of actual and immediate mathematical development of the personality are established, learner's qualitative changes in educational and mathematical activity take place, reflected in the internal and external dimensions of students' mathematical competence [10].

Sixth, the teacher's personal position is attributed to the psychological-pedagogical prerequisites for the development of structural-mathematical thinking. Ukrainian psychologist O. K. Dusavytskyi calls the teacher's personal position a "superposition in pedagogical activity", since its main goal is personality education. Such a position involves the establishment of not only subject-subject, but also interpersonal relations. In this light, the scholar maintains that going beyond the boundaries of educational activities and using other means of communication (identification, empathy) than in educational activities. At the individual level, the equality of the teacher and the student is recognized, they become equal in a moral, universal sense as "unique individuals" [13, p. 39]. The basis of such a personal position is the teacher's value system: respect and importance of understanding the student, the ability to make personal choices and the ability to take personal responsibility, the importance of ensuring the joy of learning as a creative process.

Which of the two types of pedagogical activity the teacher conducts, depends on the personal position of the teacher. The first type of activity involves a message, a story (retransmission) and a monologue, such activity focuses on the reproduction of a predetermined pattern. The other type is realized through pedagogical communication, cooperation and dialogue, and it is specifically in this way that thinking activity is actualized. It is under the second system of pedagogical actions and cooperative activities that the conditions for the development of structural-mathematical thinking are provided.

The described psychological and pedagogical conditions serve as the basis for creating an innovative type of Mathematics education, namely the developmental-conceptual one, which activates the components of theoretical thinking and ensures the development of students' structural-mathematical thinking.

The developmental-conceptual teaching of Mathematics involves the following stages:

- Step 1. Formulation of the problem \longleftrightarrow establishing the structure of the problem \longleftrightarrow determining the type of the problem.
- Step 2. Solving the problem \longleftrightarrow establishing the structure of solving the problem \longleftrightarrow determining the structure of solving typical problems.
- Step 3. Implementation of the logic of descending from the abstract to the concrete: solving partial problems.
- Step 4. Formulation of the competence problem \longleftrightarrow establishment of the structure of the competence problem \longleftrightarrow definition of the competence problem type.
- Step 5. Solving the competence problem \longleftrightarrow establishing the structure of solving the competence problem \longleftrightarrow determining the zones of actual and nearest mathematical development.

A competence problem in Mathematics involves answering the following questions:

1. How exactly should you proceed when solving typical problems in Mathematics?
2. Why do you need to do this?
3. Why do you need to solve such problems in Mathematics?

The implementation of the outlined technology is ensured in the conditions of heuristic conversation, reproductive and research methods of learning, as well as the relevant use of dynamic mathematical tools. A methodically and perfectly constructed heuristic conversation ensures the actualization of structural-mathematical thinking in the course of formulating and

solving problems for calculation and proof, for construction and research. It can be used both for group (collectively distributed) and individual forms of educational work. In this context, the professional skill of the teacher to organize a heuristic conversation, which is manifested in pedagogical and mathematical abilities, taking into account the students' level of training (zones of actual development), an appropriate sequence of questions, predicting possible answers, a whole system of prompts, successful illustrative material, is of paramount importance. The said professional skill includes variability in planning and implementation of the teaching method: the more possible scenarios for organizing a heuristic conversation, the more skillful the teacher is.

A feature of the reproductive method of learning is the reproduction of acquired knowledge and formed ways of acting according to a predetermined algorithm (learning model). The methodological expediency of using this method at the third step of developmental-conceptual teaching of Mathematics. According to the activity approach, conditions are created for two-level structural and functional transformations: at the first level – logical-mathematical operations \longleftrightarrow logical-mathematical actions, and at the second – logical-mathematical skills \longleftrightarrow logical-mathematical abilities.

The principal methodological requirement for the use of the research method of teaching is the preliminary establishment of the zones of actual mathematical development of the students of education and the creation of zones of their nearest mathematical development. It is important to determine the level of complexity, the degree of novelty, and the degree of content-theoretical generalization of the problems that students are able to cope with on their own. If the solution of the research problem is carried out in the zone of the closest mathematical development, then the developmental-conceptual teaching of Mathematics is a form of developing the structural-mathematical thinking. The methodological requirements include the system of heuristic and algorithmic prescriptions that ensure the independence of solving the research problem, as well as the expediency of using dynamic Mathematics tools, for example, the “GeoGebra” software, which plays a heuristic role and creates the basis for groundbreaking experiences during the research.

GeoGebra is software that provides the ability to create dynamic (“live”) drawings for use at various levels of Mathematics education (Geometry, Algebra, Mathematical Analysis). Such a program is used during the implementation of the second and third steps of developmental-conceptual teaching of Mathematics, in particular: establishing the structure of problem solving and in the process of solving partial problems. Its advantage is the possibility of step-by-step construction of figures, illustration of the dynamics of graph properties. The ability to animatedly change the coordinates of the points allows the figure to supposedly “come to life” on the monitor, to change its image. In fact, GeoGebra is freely distributed, has a rich mathematical toolkit, allows creating dynamic drawings, geometric models, provides wide opportunities for working with functions, for animated presentation of computer models. In view of the above, GeoGebra version 5.0 is popular in the modern educational space [14].

3.4. Experimental verification of the effectiveness of the method of developing structural-mathematical thinking

Experimental training was organized in the system of methodical training of the would-be teachers of Mathematics. The minimum sample volume, which provides reliable estimates of the parameters of the general population, was calculated according to the formula

$$n = \frac{\omega(1 - \omega)t^2}{\Delta^2},$$

in which ω – is the selective percentage ($0 < \omega < 1$), Δ – is the marginal error of the confidence interval, t – is the argument of the Laplace function based on the found confidence probability.

Assuming a confidence probability (reliability) $P(|p - \omega| < \Delta) = 0.97$, the argument value $t = 2.17$ of the Laplace integral function was obtained according to the tables. Taking into account that the expression $\omega(1 - \omega)$ acquires the greatest value at $\omega = 0.5$, and assuming the marginal error of the confidence interval $\Delta = 0.05$, the minimum sample size was calculated as follows: $n = 471$.

In the formative stage of the pedagogical experiment, 478 students took part (at the baseline), thereby meeting the statistical requirement regarding the sample size. Hence, the results with a reliability of 0.97 and a margin of error of 0.03 were extended to the entire general population. Based on the content, phenomenological characteristics, and types of structural-mathematical thinking, task sets were formulated that encompassed:

- 1) formulation of mathematical concepts;
- 2) formulation of theorems and their subsequent validation through proof;
- 3) mathematical modeling of problem situations;
- 4) educational modeling of solving typical problems;
- 5) compilation of mathematical problems;
- 6) solving competence problems.

Various levels of development in structural and mathematical thinking were assessed using a 100-point rating scale, ranging from low to medium, sufficient, and high. The highest level was identified as the “creative” tier when an unconventional task was proposed at a high level.

The instruction of control groups (CG) was conducted following the conventional (traditional) method, and experimental groups (EG) – according to the developed (experimental) method. The analysis of the results of the baseline showed that the empirical distributions in CG and EG did not differ. With that in mind, the groups were homogeneous at the beginning of the experiment. A comparison of the results of the control sections in EG and CG showed that the empirical distributions of the development of structural-mathematical thinking started to diverge following the implementation of the experimental method.

The experimental study yielded findings indicating that a mere 6% of undergraduate students from EG possess a creative level of development in the domains of structural and mathematical thinking, whereas a high level is demonstrated by 13%, a sufficient level – by 27%, an average level – by 28%, a low level – by 26%. As a result, creative, high and sufficient levels of development were shown by 46% of respondents, 54% – found medium and low levels of development (figure 4). There was a decrease in the number of students with low and medium levels of development (by 11% and 14%, respectively), and the most significant increase was the number of students with a sufficient level of development – by 17% more as compared to the first year of study.

It is worthy of note that 68% of respondents demonstrated a low and average level of structural-mathematical thinking development in undergraduates CG. Less pronounced was the tendency to decrease the number of students with a low level of development. At a sufficient level, the indicator improved by 7%, whereas the percentage of high and creative levels of development remained practically unchanged, unlike EG (figure 5). The comparative dynamics of structural-mathematical thinking of the 4th-year students is presented in figure 6 as follows.

To check the scientific validity following the completion of the experiment, the Kolmogorov-Smirnov λ -criterion and Fisher's ϕ^* -angular transformation were used. The first method made it possible to find the point at which the sum of the accumulated differences between the distributions in EG and CG was the largest, as well as to estimate the reliability of these differences. Another method is to assess the reliability of differences between percentages.

So, two alternative hypotheses are as follows: H_0 – the empirical distributions of the development of structural-mathematical thinking in CG do not differ from the empirical

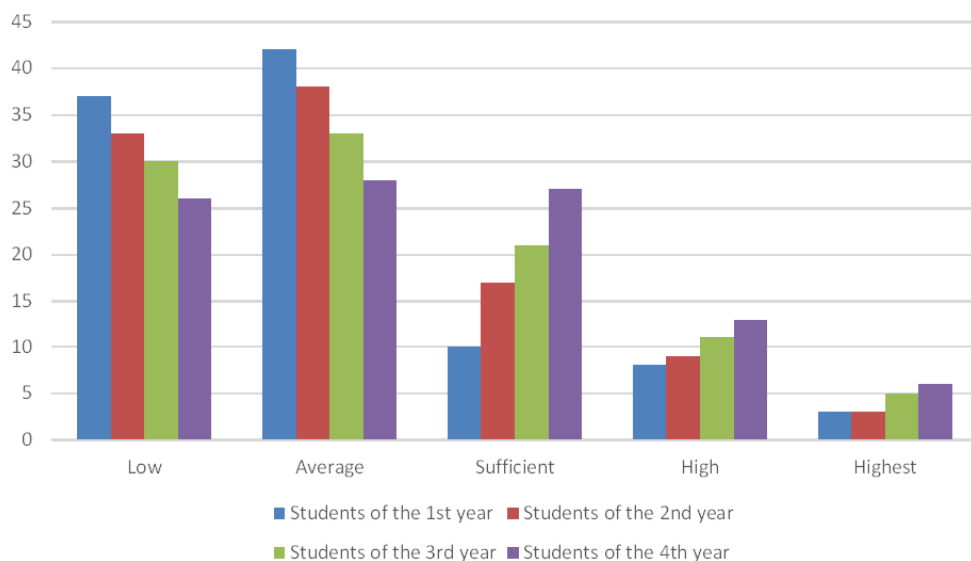


Figure 4. Indicators of the development of structural-mathematical thinking in EG.

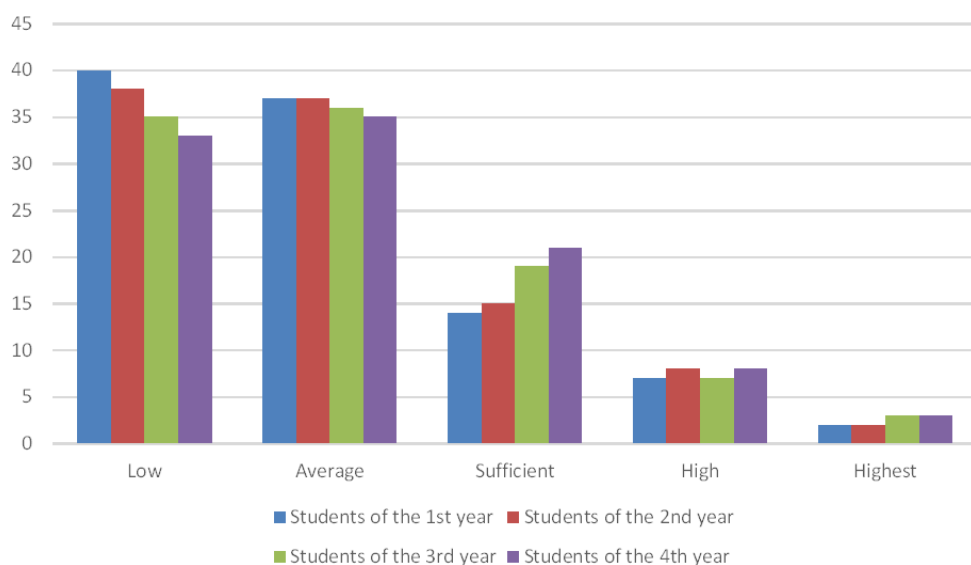


Figure 5. Indicators of the development of structural-mathematical thinking in CG.

distributions of the development of such thinking in EG; H_1 – the empirical distributions of the development of structural-mathematical thinking in CG differ from the empirical distributions of the development of the said thinking in EG. The results of the calculations are presented in the table as follows (table 1).

The value of λ -criterion is calculated using the formula:

$$\lambda = d_{max} \sqrt{\frac{n_e n_k}{n_e + n_k}} = 1.49.$$

According to the table, the obtained value $\lambda = 1.49$ corresponds to the level of statistical significance $\rho = 0.024$. Critical values λ , that correspond to the accepted levels of significance: $\lambda_{0.05} = 1.36$.

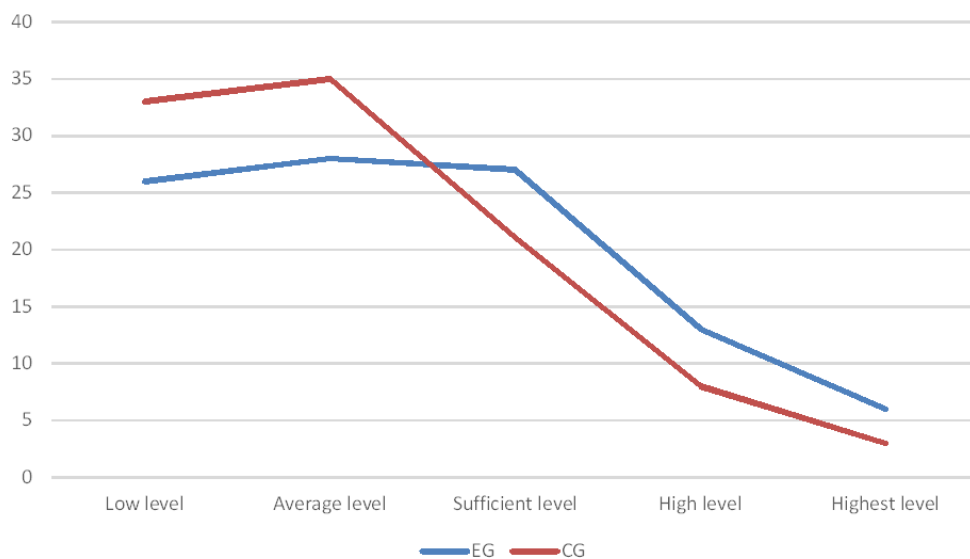


Figure 6. The dynamics of structural-mathematical thinking in EG and CG.

Table 1. Calculation of λ -criterion for comparing empirical distributions of the development of structural-mathematical thinking in EG and CG.

Levels of development	Empirical frequencies		Empirical relative frequencies		Accumulated empirical relative frequencies		Difference $d = \sum f_e^* - \sum f_k^*$
	f_e	f_k	f_e^*	f_k^*	$\sum f_e^*$	$\sum f_k^*$	
Low	63	78	0.261	0.329	0.261	0.329	0.068
Average	68	83	0.282	0.350	0.543	0.679	0.136
Sufficient	65	50	0.270	0.211	0.813	0.890	0.077
High	31	19	0.129	0.080	0.942	0.970	0.028
Highest	14	7	0.058	0.030	1.000	1.000	0.000
Total	241	237	1.000	1.000			

Since $1.49 > 1.36$, the differences between the distributions are reliable, thus the hypothesis H_1 is accepted.

Further, the reliability of the reliability of the differences between the percentages of the samples in EG and CG using Fisher’s ϕ -angle transformation is estimated. The maximum difference between the accumulated empirical frequencies was found at the middle level of development. The upper limit of this category will be used as a criterion for dividing both samples into subgroups where “there is an effect” (highest, high, and sufficient levels) and “there is no effect” (low and medium levels). The results are presented in the table as follows (table 2).

The values ϕ_1 and ϕ_2 , which correspond to the percentage shares of each group: $\phi_1(45.6\%) = 1.483$, $\phi_2(32.1\%) = 1.205$, are determined.

In such a way the empirical value of the criterion is found:

$$\phi_{emp} = (\phi_1 - \phi_2) \sqrt{\frac{n_1 n_2}{n_1 + n_2}} = 3.04,$$

where n_1 is the number of subjects in the EG sample; n_2 – the number of subjects in the CG sample.

Table 2. Calculation of Fisher’s ϕ -angular transformation for assessing the reliability of discrepancies in EG and CG.

Group	There is an effect		There is no effect		Total number of respondents
	Quantity of respondents	%	Quantity of respondents	%	
EG	110	45.6	131	54.4	241
CG	76	32.1	161	67.9	237
Total	186		292		478

The critical values ϕ^* , that correspond to the levels of statistical significance accepted in pedagogical research are as follows:

$$\phi_{cr}^* = \begin{cases} 1.64 & (p \leq 0.05), \\ 2.31 & (p \leq 0.01). \end{cases}$$

The obtained empirical values are in the zone of significance $\phi_{emp}^* > \phi_{cr}^*$, so the differences between percentages are reliable. Therefore, the hypothesis H_0 is rejected, and the hypothesis H_1 is accepted: the percentage of students who have better indicators of the structural-mathematical thinking development is greater in EG. Thus, the effectiveness of the experimental methodology for the development of structural-mathematical thinking was confirmed by the methods of mathematical statistics.

4. Results

The implementation of the experimental methodology yielded the following results:

1. EG students have a better command of the system of mathematical concepts, they are better acquainted with the main theorems and methods of their proof. In comparison with CG, students of EG have a stable dynamics in terms of establishing the structure of tasks and recognizing their types. The analytical type of structural-mathematical thinking of EG is implemented in the structural-mathematical analysis of the leading idea, mathematical concepts, the structure of theorems and problems, as well as techniques, strategies, methods of their proof and solution.
2. Qualitative changes were achieved in the process of mathematical modeling of problem situations, application of the method of mathematical modeling. The effect was ensured by the awareness and integral implementation of the EG structure of the mathematical modeling method, namely: *content analysis of the practical problem* \longleftrightarrow *formalization* \longleftrightarrow *construction of a mathematical model* \longleftrightarrow *formulation of the mathematical problem* \longleftrightarrow *finding the solution to the mathematical problem* \longleftrightarrow *interpretation of the solution*. The abstracting type of structural-mathematical thinking has undergone positive dynamics, which is manifested in the distraction from the properties that are insignificant from the point of view of Mathematics and the focusing of attention on the essential ones.
3. A positive dynamics is observed regarding the content generalization of mathematical material by EG students, their mastery of generalized methods of action in the process of solving problems. Their activities are focused, for the most part, on finding a course of action in the process of formulating mathematical concepts and theorems, as well as in the course of solving typical problems. Therefore, the organization of the educational process based on the activity theory actualizes the generalizing type of the students’ structural-mathematical thinking.

4. The planning type of structural-mathematical thinking of EG students is manifested in the content planning of the problem-solving process, the application of algorithmic and heuristic prescriptions. Educational-mathematical activity of EG predominantly involves the creation of a prospective action plan, and not obtaining a result (answers).
5. Solving of the competence problems by the EG students makes it possible to establish zones of actual mathematical development, planning zones of their immediate development. Such tasks provide acts of reflection in the teaching of Mathematics, orient to the understanding of mathematical material in the process of self-cognitive activity. Qualitative positive changes were achieved in the segment of the reflexive type of students' structural-mathematical thinking.
6. The students with high and highest (creative) levels of development of structural-mathematical thinking identified by the results of the experiment had high educational achievements, participated in mathematical Olympiads and competitions, in the work of relevant clubs and problem groups. They quickly got tired of monotonous (routine) work, sophisticated calculations, showed reluctance to act according to a defined (ready-made) pattern in the process of traditional formation of skills and abilities. In general, the search for structuredness, the focus on finding a method of action, the main idea (principle), solving problems in general and, to a lesser extent, orientation on the result (answer) characterize the activities performed by such students.

5. Conclusions

In summary, the following conclusions can be formulated:

1. The problem field includes the scientification of mathematical education regarding the content, structure, typological characteristics of the structural-mathematical thinking of the students of education as an indispensable attribute of their mathematical competence, which is a component of the personal-psychological dimension. Accordingly, scientific substantiation and methodical preparation of an innovative type of Mathematics education ensures the development of structural-mathematical thinking.
2. Structural-mathematical dimension includes a type of theoretical thinking that ensures the identification of regularities in the formation and development of mathematical objects and is based on the concept of "mathematical structure". Such cognitive activity involves a logical scheme, according to which the mathematical structure of the content is established, a structural-mathematical analysis of the educational material is performed as a type of system analysis.
3. In the personal-psychological dimension of mathematical competence, structural-mathematical thinking is combined with memory for mathematical material, experience of mathematical activity, self-awareness (self-concept of the individual) and mathematical abilities. Content-theoretical actions serve as the classification basis of structural-mathematical thinking, which made it possible to distinguish the following varieties: analytical, abstracting, generalizing, planning and reflective.
4. The psychological-pedagogical prerequisites for the development of structural-mathematical thinking of students include the organization of their educational-mathematical activity in accordance with the third type of learning and the main provisions of the theory of the step-by-step formation of mental actions and techniques of mental activity, the formation of the main indicators of each of the six dimensions of mathematical competence, the creation zones of immediate mathematical development, problem-based approach as well as teacher's stance.

5. The development of students' structural-mathematical thinking involves the development of an innovative type of Mathematics education, namely developmental-conceptual, the stages of which ensure the establishment of the componental structure and the specificity of educational-mathematical activity: the problem, solving the problem, solving typical problems, logical descent from abstract to concrete (solving partial problems), the competence problem, solving the competence problem. The implementation of such educational technology is carried out in the conditions of heuristic conversation, the reproductive and research methods of learning, as well as the appropriate use of dynamic mathematical tools.
6. The results of the experimental teaching of Mathematics prove the effectiveness of the introducing the innovative educational technology, as well as the development effect of the developed methodology. It was established that the analytical, abstracting, generalizing, planning and reflective types of the students' structural-mathematical thinking undergo positive changes.

It is expedient to develop and theoretically substantiate the methodological model, as well as to create an innovative method of implementing a problem-based approach to the development of the students' mathematical competence, which belongs to the perspective of further scientific research.

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Structural and functional model of formation of STEM-competencies of students of professional higher education institutions in mathematics teaching

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Abstract. This study focuses on the vocational preparation of learners in professional pre-higher educational establishments. The primary objective is to provide a theoretical foundation for, construct, and empirically evaluate the efficacy of a structural-functional paradigm for cultivating STEM proficiencies among students in these institutions through mathematics instruction. The pedagogical experiment corroborated the research postulate that attaining advanced STEM competencies in mathematics among professional pre-higher education students can be facilitated through a learning model that incorporates specific pedagogical conditions: motivating and stimulating students to engage in educational, cognitive and research activities in mathematics through engagement in cooperation and the use of individual and group coaching; implementation of STEM projects in mathematics teaching; usage of ICT to ensure visibility and research orientation of mathematics teaching. The experimental outcomes and accompanying educational resources have enabled a comprehensive analysis of the challenges associated with implementing STEM methodologies in mathematics instruction. This article aims to elucidate the key attributes of the devised structural-functional model and evaluate its implementation efficacy, with particular emphasis on the application of the authors' developed pedagogical support materials.

1. Introduction

STEM education is one of the most important areas of education reform in Ukraine. The development of STEM competencies among young people can help bridge the gap between education and the demands of modern life. The implementation of STEM education will help to prepare a professional armed with innovative teaching technologies, practical personal experience that will satisfy the social order of society [1]. In the context of integration and mobility, the educational paradigm requires new approaches to learning, including mathematics. It is important to search for innovative methods that will help to form a personality capable of solving complex problems. Motivating and stimulating students to educational, cognitive and research activities in mathematics teaching are considered as important pedagogical conditions in the context of the general problem of forming STEM competences of professional junior bachelors [2].



1.1. Theoretical foundation

The conceptual frameworks and practical implementations of STEM education in Ukraine have been explored by various researchers [3–7]. Contemporary challenges in STEM education and the development of STEM project roadmaps are addressed in the handbook by Polihun et al. [8].

Pedagogical models centered on fostering STEM competencies in teacher training are presented by Balyk et al. [9] and Valko and Osadchyi [10,11]. Kuzmenko [12] dedicates significant attention to advancing STEM education within physics instruction.

Dynamic mathematics systems, particularly GeoGebra, are examined as engineering instruments by several scholars [13–15]. Kramarenko et al. [16] elaborate on the features of the GeoGebra 3D Calculator mobile application, which incorporates augmented reality to enhance mathematics teaching methodologies through cloud technologies.

Kuzmich et al. [17] investigate methodologies for studying metric spaces' geometric properties. They propose constructing analogues in two-dimensional and three-dimensional Euclidean arithmetic spaces to geometrically interpret the linear and planar arrangement of metric space points. The GeoGebra 3D dynamic geometric environment is recommended for concept visualization.

The application of immersive technologies in education, particularly within the STEM context, has been extensively researched [18–30].

STEM competencies are defined as a dynamic system encompassing knowledge, abilities, skills, thought processes, values, and personal attributes that foster innovative capacity. These competencies encompass the ability to tackle complex issues, develop critical thinking, creativity, organizational aptitude, emotional intelligence, and cognitive adaptability. Teamwork, decision-making, and effective interaction skills are also crucial.

However, a review of scientific literature reveals a scarcity of research on developing STEM competencies among professional college students. There is also limited exploration of higher education institutions' faculty involvement in enhancing training quality through STEM education.

An analysis of scientific sources and pedagogical practices has unveiled several contradictions in modern education:

- (i) A disparity between the extensive domestic and international experience in implementing STEM education at the secondary level and the inadequate recognition of its necessity and relevance for professional junior bachelors.
- (ii) A mismatch between the expected STEM competency levels of professional higher education graduates and their actual attainment.
- (iii) A lag in curricular updates and methodological support for professional junior bachelors, despite the need for innovation driven by digitalization and European integration processes.

1.2. Article aims and objectives

The significance of this research is underscored by the swift progression of STEM education, alongside transformations in economic landscapes, technological infrastructures, and organizational structures. These changes are reshaping the knowledge and skill requirements for professional junior bachelors.

This article's primary objective is to elucidate the distinctive characteristics of the structural and functional model of formation of STEM-competencies of students of professional higher education institutions in mathematics teaching and to assess its implementation efficacy. Particular emphasis is placed on the application of the authors' custom-developed instructional and methodological resources.

2. Results

Based on a comprehensive review of scientific and pedagogical literature, as well as educational practices, the authors have refined the conceptualization of STEM competencies for students in professional higher education institutions.

STEM competencies are characterized as an integrated personal construct, manifesting through the development of several key components:

- Mathematical proficiency
- Information and communication technology skills
- Foundational competencies in natural sciences and technology
- Project management and technological aptitude
- Soft skills, with a particular emphasis on critical thinking

The research team conducted an analysis of professional higher education standards across various disciplines, including Information, Library and Archival Affairs (029), Finance, Banking, Insurance and Stock Market (072), Accounting and Taxation (071), Business and Trade (076), and Food Technologies (181). This analysis identified competencies that students can develop through STEM disciplines, particularly mathematics. General STEM-related competencies include the ability to apply knowledge practically, utilize information and communication technologies, and effectively search, process, and analyze information from diverse sources.

For instance, specialty-specific competencies for students in Finance, Banking, Insurance and Stock Market (072) that align with STEM principles include:

- Utilizing theoretical and methodological tools from finance, economics, mathematics, statistics, law, and other relevant disciplines to address complex financial, banking, and insurance challenges
- Employing modern information systems and software for data acquisition and processing in finance, banking, and insurance
- Facilitating effective communication between specialists and service users in the financial sector

The study revealed that addressing existing contradictions is feasible through the establishment of specific pedagogical conditions, namely:

- motivating and stimulating students to engage in educational, cognitive and research activities in mathematics through engagement in cooperation and the use of individual and group coaching
- implementation of STEM projects in mathematics teaching
- usage of ICT to ensure visibility and research orientation of mathematics teaching

Three groups of external factors influencing STEM education actualization were identified:

1. Societal demand for highly qualified STEM professionals
2. Advancements in information, communication, and STEM technologies, including the development of specialized and adapted teaching tools for mathematics
3. Methodological considerations, encompassing teaching principles, fundamental learning organization approaches, and the modernization of instructional technologies and methods

The authors have developed and theoretically substantiated a structural and functional model of formation of STEM-competencies of students of professional higher education institutions in mathematics teaching (figure 1), grounded in scientific concepts of educational goals, objectives, and content [2]. The model's effective implementation is predicated on various approaches to learning, including project-based, research-oriented, competency-focused, activity-centered, personality-oriented, cognitive, synergistic, differentiated, and systematic methodologies. Educators are advised to adhere to principles such as scientific rigor, accessibility, developmental appropriateness, integration, cognitive engagement, individuality, research and practical orientation, theory-practice interconnections, learner independence and activity, interactivity, and metacognitive awareness throughout the instructional process.

The structural and functional model of formation of STEM-competencies of students of professional pre-higher education institutions in mathematics teaching is comprised of four interconnected components: target, content, activity, and diagnostic blocks.

The target block delineates the primary objective: cultivating STEM competencies among students in professional pre-higher education institutions through mathematics instruction.

The content and activity blocks elucidate the process of developing students' STEM competencies in mathematics education. These blocks encompass:

- The conceptual framework of students' STEM competencies
- Pedagogical conditions conducive to competency development
- Educational resources and methodologies
- Instructional approaches and formats

The diagnostic block outlines assessment tools based on carefully crafted criteria:

- Value-motivational
- Creative and active
- Cognitive
- Reflective-evaluative

These criteria serve as indicators for evaluating the formation of students' STEM competencies. The model employs a four-tiered classification system to gauge competency levels:

1. High
2. Sufficient
3. Intermediate
4. Elementary

In teaching mathematics to first- and second-year students of professional pre-higher education institutions using STEM approaches, it is advisable to follow the curriculum for grades 10-11 and its coverage in modern textbooks. Textbooks of the standard level were used in the teaching, in particular, by Merzliak et al. [31].

The authors made extensive use of the visualizations developed by Mathematics in STEM [13] to visualize abstractions using the GeoGebra dynamic mathematics system [32].

In order to determine what motivates college students to study mathematics, what they know about STEM education, and the use of ICT in teaching mathematics, it is advisable to conduct a survey to determine their level of motivation through STEM education. The analysis of the study results makes it possible to analyze not only the levels of students' motivation in learning mathematics, but also to establish that one of the important pedagogical conditions for the effective implementation of STEM education is to motivate and stimulate students to engage in

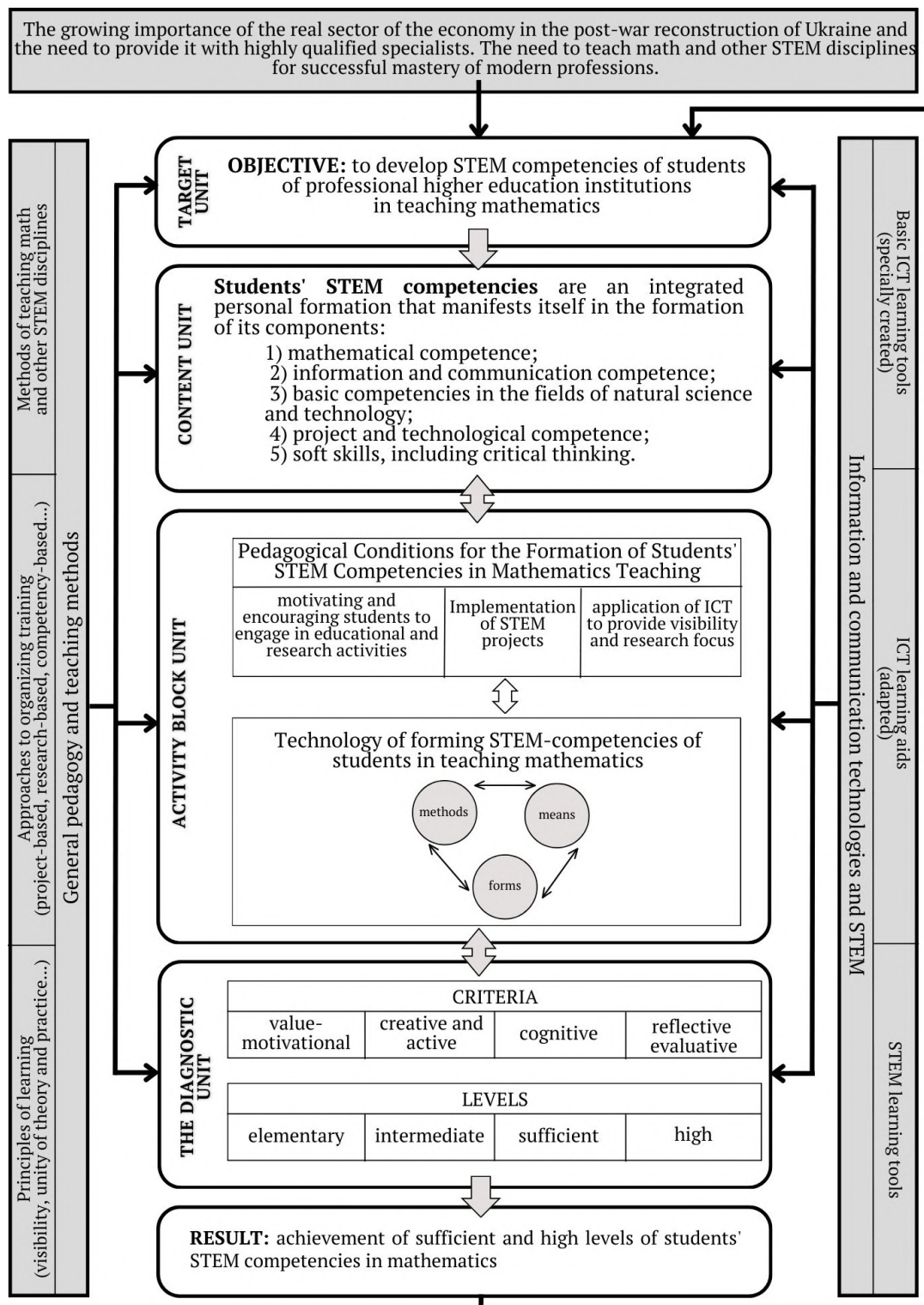


Figure 1. Structural and functional model of formation of students' STEM competencies in mathematics teaching

educational, cognitive and research activities in learning mathematics through engagement in cooperation and the use of individual and group coaching.

Here are the examples from our experience of motivating and stimulating students to engage in educational and research activities in mathematics. The most important thing for motivating students to do research is the personal significance of the chosen task for each of them. For example, when studying the elements of mathematical statistics, it is advisable to offer the following task.

1. Find out the ratio of a student's height to his/her weight. Using the Courel formula, calculate whether the student's mass corresponds to his height. To do this, divide the weight measured in kilograms by the square of the height measured in meters. If the ratio is less than twenty, then weight needs to be gained. If the value of the calculated value is between 20 and 23, then the weight is normal. For those students whose calculated ratio is greater than 24 but not greater than 29, it is advisable to lose weight.
2. Investigate the body mass index of your own family members, and conclude how balanced the family's diet is. The project theme can be formulated more broadly – Math in the Kitchen.
3. How is mathematics, in particular statistics, used in agriculture, in the transportation industry, in construction, and in the student's future profession?
4. How efficiently is the garden or garden plot, if any, used by your family?

Considering the methodology of forming students' STEM competencies in mathematics, we distinguish the following main areas of STEM approaches:

- development and implementation of educational projects, including STEM projects that can be transdisciplinary;
- conducting binary and integrated classes that connect mathematics with other academic disciplines, including computer science, physics, economics, and statistics;
- use of dynamic mathematics systems, such as GRAN and GeoGebra, and other engineering tools for graphing functions, solving equations, inequalities, visualizing abstractions, etc;
- application of software tools for solving problems requiring statistical data processing;
- use of augmented reality;
- introduction of research tasks and applied tasks into the content of training.

Success in STEM mathematics education for finance students depends on the implementation of modern methods and pedagogical innovations. One of the key aspects is the integration of mathematical concepts into financial disciplines, that allows students to see the connection between theory and practice. Let's look at some examples of using educational projects as a basis for implementing STEM education in teaching mathematics to students of professional colleges. An example may be the use of mathematical models for risk analysis and financial decision-making, calculating interest rates and loans, studying investment strategies and trading operations.

Bank employees and citizens who keep money in a bank at interest or take out a loan deal with interest calculation formulas. Therefore, the user needs to familiarize himself with the lending terms of different banks in advance and be able to assess which bank is the most profitable to take out a loan from. The practical result of the project can be a report on the banks available in the region on the effectiveness of taking out a cash loan, a loan for a new home or a car, etc.

We have successfully engaged college students in the STEM project "Creating a 3D hologram". A hologram is a projection of an image of an object from a plane into three-dimensional space. This creates the illusion of three-dimensionality, since a person does not see the objects themselves, but only their light images. The proposed project is interdisciplinary.

In the math class, while studying the topic “Sections of polyhedra,” students were asked to make a model of a regular cut quadrilateral pyramid. Plastic plates were the material for the model. First, students made markings on the plate, then cut and glued the model (figure 2). To check the work, they opened the finished 3D hologram video on their phones and placed the inverted model on top.

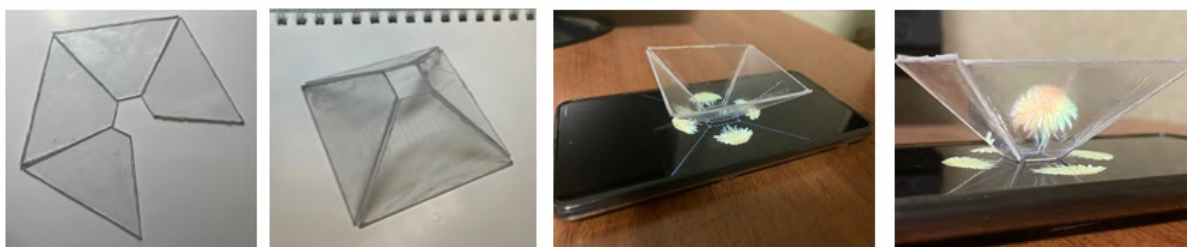


Figure 2. Photo for the Hologram project.

Based on the evaluation results, the following enhancements have been incorporated into the mathematics curriculum for professional pre-higher education institutions:

- Diverse educational formats, including ICT integration, STEM projects, STEM quests, web conferences, blogs, websites, and subject-specific social media groups
- A comprehensive package of methodological resources
- A system of applied tasks and game-based, professionally-oriented scenarios
- Assessment tools for monitoring the development of students’ STEM competencies in mathematics education

To validate the efficacy of the structural and functional model of formation of STEM-competencies of students of professional pre-higher education institutions in mathematics teaching and its associated pedagogical conditions, a rigorous pedagogical experiment was conducted. Additionally, a diagnostic methodology was implemented to evaluate the effectiveness of the proposed tools.

The research spanned a four-year period (2019-2023) and was executed in four distinct phases:

1. Preparatory stage (2019-2020): This phase involved a theoretical examination of the need for STEM competency development among students in professional pre-higher education institutions, specifically in mathematics education.
2. Stating stage (2020-2021): The objective of this phase was to establish a baseline measurement of STEM competency levels among students at the outset of the experiment.
3. Formative stage
4. Control stage

Students of two groups of the specialty 072 “Finance, banking and insurance” of Separate structural unit “Kryvyi Rih Professional College of State University of Economics and Technology” took part in the experimental study. The formative stage (2021-2022) was conducted with the aim of implementing the model and determining the level of formation of STEM-competencies of students of institutions of professional pre-higher education in teaching mathematics at the end of the experiment.

The control stage (2022-2023) provided the systematization of the results of the experiment, their statistical processing, analysis and formulation of conclusions.

To conduct the experiment, we formed a control group (40 students, CG) which was offered the traditional training and an experimental group (40 students, EG), which was taught with the introduction of the model implementation. After that, students were re-assessed with help of questionnaires, tests and control papers [13]. As a result we compared the levels of formation of individual components of students’ STEM competencies in mathematics learning (value-motivational component; creative and active component; cognitive component; reflective-evaluative component) at the stating and formative stages of the experiment.

For example, let’s check the reliability of the study results on the growth of the share of the sum of the sufficient and high levels of formation of the value-motivational component of students’ STEM competencies at the beginning and end of the experimental study. The survey was conducted according to the questionnaire, which is presented in the manual Mathematics in STEM [13], summarized results regarding levels are presented in table 1.

Table 1. Value and motivational components of students’ STEM competencies in Mathematics learning in the experimental and control groups.

The level	Before the experiment		After the experiment	
	experimental group	control group	experimental group	control group
Elementary	5 (12.5 %)	4 (10 %)	3 (7.5 %)	3 (7.5 %)
Intermediate	19 (47.5 %)	20 (50 %)	6 (15 %)	20 (50 %)
Sufficient	11 (27.5 %)	12 (30 %)	19 (47.5 %)	12 (30 %)
High	5 (12.5 %)	4 (10 %)	12 (30 %)	5 (12.5 %)
Total	40 (100 %)	40 (100 %)	40 (100 %)	40 (100 %)

We compared the shares before and after the experiment using the Fisher’s angular transformation (table 2), for the value level $\alpha = 0.05$. At the stating stage of the experiment, it was established that the indicator of the sum of the sufficient and high levels of formation of the value-motivational component of the STEM-competencies of the CG students does not differ from the corresponding indicator of the EG. The significance level is 5 % the empirical value of the criterion at the end of the experiment is 3.286, which exceeds the critical value of 1.64. This means that the null hypothesis should be rejected: the indicator of the sum of the sufficient and high levels of formation of the value-motivational component of students’ STEM competencies in mathematics learning in CG at the end of the experiment is significantly lower than the same indicator of EG at the end of the experiment.

Similar conclusions were drawn for other components of STEM competencies as well.

Table 2. Results of the study using Fisher’s angular transformation for the value-motivational component formation.

Groups	Sufficient, high	Total	Share	Empirical, critical
CG Stating stage	16	40	0.4	ϕ empirical = 0
EG Stating stage	16	40	0.4	ϕ critical = 1.64
CG Formation stage	17	40	0.43	ϕ empirical =3.286
EG Formation stage	31	40	0.78	ϕ critical = 1.64

3. Conclusions

The implementation of the structural and functional model of formation of STEM-competencies of students of professional pre-higher education institutions in mathematics teaching, along with the associated pedagogical conditions, has yielded significant positive outcomes. The study demonstrates marked improvements across various dimensions of STEM competencies:

- Critical thinking skills
- Information and communication competence
- Project management and technological aptitude
- Core mathematical proficiency
- Fundamental competencies in natural sciences and technology

Statistical analysis of the experimental results reveals a consistent trend of positive changes aligned with the predefined criteria for STEM competency formation. Notably, a substantial proportion of students achieved sufficient and high levels of STEM competencies in mathematics.

The research substantiates that the integration of ICT in mathematics instruction, particularly in enhancing visualization and promoting research-oriented learning, significantly contributes to the development of STEM competencies among students in professional pre-higher education institutions.

The study establishes that effective STEM education implementation can be achieved through various strategies:

- Engaging students in independent research activities
- Integrating topics across different academic disciplines
- Implementing interdisciplinary projects
- Organizing scientific “picnics”, themed days and weeks, and STEM festivals
- Facilitating holistic approaches to studying the world

The pedagogical experiment, conducted over four years (2019-2023), validated the effectiveness of the proposed model and methodologies. The study employed a rigorous four-stage approach: preparatory, stating, formative, and control stages, each contributing valuable insights to the research outcomes.

Future research directions could include:

- Developing methodological principles for incorporating immersive technologies in mathematics instruction
- Designing and implementing training programs for STEM educators in professional pre-higher education institutions
- Investigating long-term impacts of STEM competency development on students’ career trajectories
- Exploring the potential of adaptive learning technologies in personalized STEM education

These areas represent promising avenues for further scientific inquiry, potentially leading to more advanced and tailored approaches to STEM education in professional pre-higher institutions.

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Informed consent was obtained from all individual participants included in the study. Participants were informed about the purpose of the research, the voluntary nature of their participation, and their right to withdraw at any time without consequence. All data collected were anonymized to protect participant privacy. The researchers ensured that the study design and implementation adhered to the principles of beneficence, justice, and respect for persons throughout the research process.

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Comparison of the experience of using digital games in mathematics education in Ukraine and Israel

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Abstract. The study examined the opinion of school students regarding the expediency and possibilities of using digital mathematical games in the process of teaching mathematics, and also carried out a comparative analysis of the results of the research conducted in Ukraine and Israel. The issue of the distribution of digital mathematical games in Ukraine and Israel was studied, and it was found out which digital mathematical games are the most popular in the process of teaching mathematics to students in schools in these countries. It was found that the vast majority of students from these countries played digital mathematical games. In the study of students' interest in playing digital mathematical games, the questions were whether students played digital mathematical games, whether their mathematics teachers used digital mathematical games in mathematics lessons, whether students would like to use digital mathematical games when learning mathematics at school. Also, most students responded that their teachers used digital math games in math lessons and would like their teachers to continue using them. However, despite a relatively high percentage of students who are interested in using digital math games in math lessons, there are students who consider traditional math lessons to be more appropriate. It was established that there is a statistically significant difference between the results of a survey of schoolchildren in Ukraine and Israel regarding the expediency of using mathematical digital games in teaching mathematics: with a probability of 95% more surveyed schoolchildren in Ukraine (9.6%) are supporters of traditional teaching of mathematics (without the use of digital games), compared to 2.4% of surveyed schoolchildren in Israel. The statistical significance of the differences in the answers of students of the schools of these countries was checked using the ϕ^* -Fisher criterion. As a result of the research, it was found that the interest of schoolchildren of both countries in the use of digital mathematical games in the learning process is growing. Almost half of the respondents in these countries expressed the opinion that they would be interested in learning more about digital math games and trying to play them. However, there remain a number of unresolved important issues related to the methodology of this process, including didactic ones.

1. Introduction

Throughout the world, during the previous decades, the processes of digitalization in various spheres of society's life have developed rapidly [1]. Education was not an exception [2]. The impetus for the acceleration of digitalization of education was the forced transition to distance learning associated with the COVID-19 pandemic [3–5]. The participants of the educational process were forced to massively use various online resources (such as distance learning systems,



online platforms for studying various academic disciplines, programs for conducting video conferences, electronic magazines, etc.). In addition, there has been an increased interest in educational digital games [6–8], in particular mathematical games, both on the part of teachers and on the part of students [9].

Research by scientists around the world on the use of digital games in the learning process began in the 1970s. In Ukraine, these questions began to be actively studied by scientists in the 21st century. For example, conferences on Game Based Learning are regularly held, annual online game competitions are organized in certain disciplines. In particular, the creation of educational game software for algebra at the world level is supported. There are also mathematical curricula that are completely based on the principles of the video game and are in use.

Scientists are conducting research on the influence of digital games on the process of learning mathematics for students of different age groups, in particular:

- primary school [10–18];
- high school [19–21].

Most researchers note the positive influence of digital games on the process of learning mathematics of students in primary and secondary schools.

The study of Thai et al. [17] presents the results of using the My Math Academy digital game in the process of teaching mathematics to primary school students. The authors note the positive impact of this game on the level of knowledge, interest and confidence of students in learning mathematics.

Yang et al. [16] examined the issue of improving the performance of primary school students in mathematics learning with the help of mobile games. This study proposes an interactive mobile mathematical game with a help-seeking mechanism to improve students' mathematical achievement, learning motivation, and social interactions. Based on the obtained empirical results, the authors note that the proposed approach benefited students with low self-efficacy more than students with high self-efficacy, which indicates the high potential of this approach to help students with low self-efficacy improve their mathematical training.

Bullock et al. [15] studied the relationships between semiotic representational transformations and performance outcomes in digital mathematical games of 4th, 5th, and 6th grade students. The results of the study showed that some digital mathematical games elicited more representational transformations than others. These results show the importance of recognizing and using semiotic representations and representational transformations for mathematics learning outcomes when students play digital mathematics games.

The study of the impact of digital games on the process of learning mathematics is diverse, as evidenced by the scientific works of many researchers.

So Ng et al. [22] studied the issue of anxiety in learning mathematics and how to eliminate it with the help of a digital learning program in mathematics for students of the first and second grades. Researchers evaluated whether intensive mathematics learning through digital games can reduce the anxiety that can occur during mathematics learning. The article concludes that learning distress can be alleviated with short-term intensive learning using digital games.

Also important are the studies [14,18,23,24] on the results of using mathematical digital games in the process of learning mathematics depending on the gender of the students. McLaren [24] studied the use of Decimal Point, a digital educational game for 5th and 6th grade students. Several studies with different versions of the game involving more than 800 students over the years have shown the benefits of teaching girls through play [24]. In additional results presented in the article, the authors found a gender effect, which was manifested in the fact that girls acquired more mathematical knowledge from the game than boys [24]. It was also found that girls made fewer mistakes [24].

Researchers pay attention not only to the role of digital games in increasing motivation for learning, but also emphasize their developmental nature in human mental processes, such as perception and memory. The results of research by Che Mansor and Rosly [25] show that the use of digital games in the process of teaching mathematics has a significant effect on improving students' perception and memorization of educational material. Thus, positively influencing the success of students in education. The authors also emphasize gender differences in the perception of material using digital games.

Joung and Byun [26] conducted an exploratory study to assess the quality of digital mathematical games and their compliance with NCTM (National Council of Teachers of Mathematics, USA) standards. In this work, a classification of digital mathematical games by types of student activities is carried out, which can help stakeholders in mathematics education to determine which digital mathematical games should be used for students to improve their knowledge of mathematics and to form criteria for evaluating the content of mathematical games in accordance with NCTM standards.

Many scientific publications describe both the mathematical games themselves and the knowledge and skills that can be acquired in the course of mathematical games. For example, Babo et al. [27] presented the platform MATHematics Digital Escape Rooms – MATH-DIGGER, which is an Erasmus+ project and is designed to expand the opportunities of students in the learning process. MATH-DIGGER aims to provide a stimulating and innovative learning and teaching practice using quest rooms. The development of mathematics curricula, including educational games and new assessment tools, is considered [27].

Scientists have also investigated the process of creating games, in which both software developers of digital computer games and students and teachers are involved: a kind of feedback that helps to improve computer games for educational needs [28–31]. A significant amount of research on digital game-based learning today allows for a more in-depth analysis of this type of learning, adjusting the process, selecting and developing educational games, taking into account interdisciplinary research, including psychology.

However, despite the growing interest in and direct use of digital mathematical games, the methodical support of the educational process remains insufficiently developed [32, 33]. At the same time, scientific publications consider the possibility of developing computer didactic games by informatics teachers, which requires them to have basic knowledge of environments for developing such games [34–36]. Although these questions are still open and require additional research, since the development of digital games, first of all, takes a lot of time and effort, and in some cases, significant funds, and it is much more economical to use ready-made (available in free access) products. In addition, today it is difficult for the majority of teachers (even computer scientists) to develop computer didactic games, however, they have knowledge, possess skills and can use them in the educational process [37]. Research of this nature once again emphasizes the relevance of the researched question regarding the use of digital games during the study of disciplines, in particular, mathematics.

Israeli scientists Hayak and Avidov-Ungar [38] considered the possibilities of training teachers to use digital games in the learning process, including mathematics, in elementary school. They found that the majority of teachers plan to implement digital game-based learning in their classrooms using a structured, orderly step-by-step approach, while some teachers prefer a flexible planning template that allows changing the order of steps.

Also worthy of attention are the explorations of Israeli researchers in the direction of studying the opinion of parents regarding the use of digital games in teaching students mathematics as an alternative to traditional homework [39].

Alabdulaziz [40] investigated the question of whether COVID-19 became a catalyst for digital learning, in particular, the use of gamification in mathematics education. The study revealed that 98% of the respondents (mathematics teachers) believe that COVID-19 contributed to

the acceleration of the development of digital gamification of mathematics education and that the use of computer games significantly increased after the start of the pandemic [40]. Israeli researchers Marbán et al. also hold a similar opinion [41].

However, so far there are not enough studies in which the aspirations and motivation of students regarding the use of digital games in the process of learning mathematics have been studied. Therefore, it is deemed worthwhile to conduct research on the use of digital mathematical games, interests, aspirations, and motivations of students in both Ukraine and other countries (particularly Israel).

The purpose of the article is to investigate how widespread the use of digital games is in the process of teaching mathematics in Ukraine and Israel, to study the opinion of students regarding the feasibility and possibilities of using digital games in teaching mathematics.

2. Methodology

Methods and approaches were used in the research: analysis, synthesis, and other methods, in particular, system analysis for the purpose of determining the structure of the research, in particular, setting the problem, interrelationship of structural elements of the research, forming conclusions; observation, measurement, questionnaire, comparison to study the researched problem; mathematical modeling, statistical and other methods for the formalization of the problem and the frequency of manifestation of the investigated effect; person-oriented, competence-based, activity-based, differentiated and other approaches for determining educational components that will contribute to achieving optimal research results.

2.1. Data collection methods

Questionnaires were used to conduct research and experimental work.

The questionnaire consisted of three parts. The first part of the questionnaire made it possible to collect demographic data of respondents, such as gender, age, educational institution, place of residence.

The second part of the survey was aimed at determining the level of students' awareness of available mathematical educational computer games.

The third part of the survey is directly related to the students' desire to learn more about the variety and possibilities of using mathematical computer games in the educational process, which made it possible to assess the students' interest in this topic. In the third part, respondents had the opportunity to choose several answers in one question, as well as express their own comments.

2.2. Data collection technique

This study was conducted in accordance with the ethical standards for research involving human participants. Prior to commencing the research, ethical approval was obtained from the institutional review board of Vinnytsia Mykhailo Kotsiubynskyi State Pedagogical University (approval number: VSPU-2023-042).

The survey was conducted using GoogleForm in online mode. Research and experimental work on the study of the distribution, feasibility and possibilities of using digital games in teaching mathematics was carried out in 2023:

- All participants (and their legal guardians for minors) were provided with detailed information about the study's purpose, procedures, potential risks and benefits, and their rights as participants. Written informed consent was obtained from all participants or their legal guardians before data collection.
- Participants were informed that their participation was entirely voluntary and that they could withdraw from the study at any time without any negative consequences.

- All data collected was anonymized and stored securely, and no personally identifiable information was included in the analysis or reporting of results.
- All digital data was stored on password-protected Google Drive account, and accessible only to the research team.
- The study was designed to pose minimal risk to participants, involving only a questionnaire about their experiences and opinions on digital mathematical games.
- The research design and implementation took into account the cultural contexts of both Ukraine and Israel, ensuring that questions and procedures were appropriate and respectful.

2.3. Respondents' demographic data

The survey of students was conducted in Vinnytsia and Chernivtsi regions, which are located in the central and western regions of Ukraine, which brings geographic diversity to the sample and, accordingly, more widely represents the opinions of Ukrainian schoolchildren. A survey of Israeli schoolchildren from the city of Kiryat Yam was also conducted.

185 students from Ukraine and 77 students from Israel participated in the survey.

The average age of Ukrainian respondents who took part in the survey was 12.8 years. Boys made up almost half of the respondents (45.4%, $n = 83$), respectively, girls – 54.6% ($n = 102$).

The average age of Israeli schoolchildren who took part in the survey was 12.7 years. Girls made up 42.5% ($n = 31$), boys – 57.5% ($n = 42$).

Note that Ukrainian and Israeli students from different grades from 5 to 11 took part in the survey.

2.4. Statistical and mathematical modeling methods

Statistical data processing was carried out using the Microsoft Excel program.

For the purpose of comparative analysis of research results, R. A. Fisher's angular transformation (ϕ^* -Fisher) was used.

The ϕ^* -Fisher criterion is employed to compare the frequency of a studied effect between two samples. This comparison necessitates formulating two hypotheses:

H_0 : With a probability of $1 - p$, it can be asserted that the proportion of the studied group of persons in which the studied effect was manifested in sample №1 is no more than in sample №2.

H_1 : With a probability of $1 - p$, it can be asserted that the proportion of the studied group of persons in which the studied effect manifested itself is greater in sample №1 than in sample №2.

p is the significance level. The study will adopt significance levels of $p = 0.05$ and $p = 0.01$. The critical value of ϕ^* for the significance level $p = 0.05$ is $\phi_{cr,0.05}^* = 1.64$. The critical value of ϕ^* for the level of significance $p = 0.01$ is $\phi_{cr,0.01}^* = 2.31$.

The empirical value of ϕ_{emp}^* is found by the formula (1) [42]:

$$\phi_{emp}^* = 2 \cdot \left| \arcsin \sqrt{PS_1} - \arcsin \sqrt{PS_2} \right| \cdot \sqrt{\frac{n_1 \cdot n_2}{n_1 + n_2}}, \quad (1)$$

where PS_1 and PS_2 are the percentage shares of the studied groups of persons in which the studied effect was manifested, respectively, sample №1 and sample №2; n_1 and n_2 are the sizes of the studied groups.

If the empirical value of ϕ_{emp}^* is greater than ϕ_{cr}^* ($\phi_{emp}^* > \phi_{cr}^*$), then the H_0 hypothesis is rejected with a probability of $1 - p$ and the H_1 hypothesis is accepted. That is, with a probability of $1 - p$, it can be asserted that the share of the studied group of persons in which the studied effect manifested itself is statistically significantly greater in sample №1 than in sample №2.

Otherwise, the H_0 hypothesis is accepted.

3. Results and discussion

3.1. Comparative analysis of the results of a survey of respondents regarding the interest of Ukrainian and Israeli schoolchildren in digital games in general and, in particular, in relation to mathematical digital games

Examining the responses of Ukrainian and Israeli schoolchildren to a questionnaire on digital games can offer valuable insights into the overarching trends of digital game interest among school-aged children. The results of observations are presented in table 1 and figure 1.

Table 1. The data of the ϕ^* -Fisher test of the statistical significance of the difference in survey results regarding the interest of Ukrainian and Israeli schoolchildren in digital games in general.

Variants of answers	Answers of Ukrainian schoolchildren, %	Answers of Israeli schoolchildren, %	ϕ_{emp}^*	ϕ_{cr}^* , (p)	The accepted hypothesis
Question: How often do you play digital games (especially on your phone)?					
A) every day	41.2	74.0	2.58	2.31, (p = 0.01)	H_1
B) several times a week	32.6	16.9	2.12	1.64, (p = 0.05)	H_1
C) several times a month	7.0	3.9	0.96	1.64, (p = 0.05)	H_0
D) several times a year	2.1	0.0	–	–	–
E) used to play, but now I don't play	17.1	5.2	2.60	2.31, (p = 0.01)	H_1

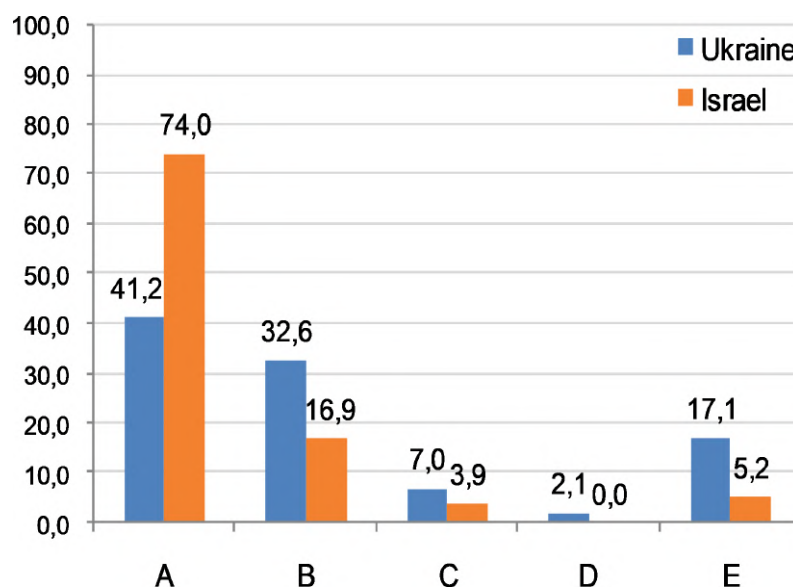


Figure 1. A bar chart showing the results of a survey on the interest of Ukrainian and Israeli schoolchildren in digital games in general (table 1).

It turned out that the number of Israeli schoolchildren who play computer games every day (74%) is almost twice as high as the number of Ukrainian schoolchildren (41%) according to this indicator. At the same time, the number of Ukrainian schoolchildren playing several times a week (32.6%) is twice as large as the number of Israeli schoolchildren (16.9%). Among Ukrainian schoolchildren, there are more people who used to play digital games, but now do not.

The statistical significance of the difference in Ukrainian and Israeli schoolchildren’s survey results will be analyzed using R. A. Fisher’s angular transformation (table 1).

Thus, according to the survey data (table 1), it can be claimed that there are statistically significantly more of them in the studied groups of respondents, with a probability of 99%, Israeli schoolchildren (74.0 %), compared to Ukrainians (41.0%), play digital games every day (in particular, on the phone), also 17.1% of Ukrainian schoolchildren compared to 5.2% of Israeli schoolchildren – used to play and now do not play In the studied group of respondents, statistically significantly more, with a probability of 95%, Ukrainian schoolchildren (32.6%), compared to Israeli (16.9%), play digital games (in particular, on the phone) several times a week, there is also no statistically significant difference between groups of Ukrainian (7.0%) and Israeli schoolchildren (3.9%) in that they play several times a month. According to the requirements of applying the ϕ^* -Fisher criterion, in case D), these requirements are not met, because 0 of answers were received in the studied group of respondents from Israel.

Students’ interest in mathematical digital games was determined using three questions (“Have you ever played digital mathematical games?”, “Have your math teachers used digital mathematical games in math lessons?”, “Would you like computer math games to be used in school when learning mathematics?”). The results of the observations are presented in table 2 and in figure 2, figure 3, and figure 4. Note that the majority of Ukrainian schoolchildren (67.9%) played mathematical digital games; in general, this advantage is not significant. However, it was Israeli teachers who used digital math games more often in mathematics lessons. There were almost twice as many Israeli schoolchildren who gave a positive answer to the question “Did your teachers use digital mathematical games in mathematics lessons?” (32.5%) than Ukrainian ones (17.1%).

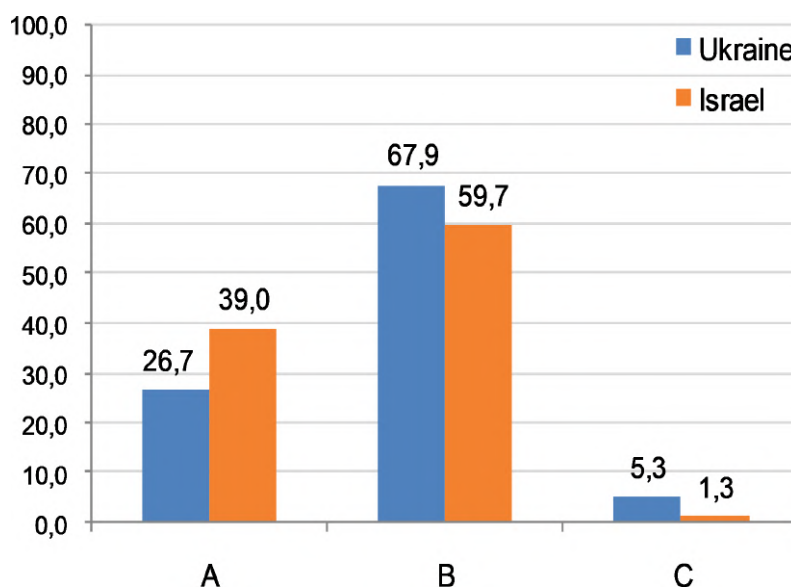


Figure 2. A bar chart showing the results of Ukrainian and Israeli schoolchildren’s answers to the question “Have you ever played digital mathematical games?” (table 2).

Table 2. The data of the ϕ^* -Fisher test of the statistical significance of the difference in results of the survey of respondents in relation to mathematical digital games.

Variants of answers	Answers of Ukrainian schoolchildren, %	Answers of Israeli schoolchildren, %	ϕ_{emp}^*	ϕ_{cr}^* , (p)	The accepted hypothesis
Question: Have you ever played digital mathematical games?					
A) I didn't play	26.7	39.1	1.38	1.64 (p = 0.05)	H_0
B) I used to play such games	67.9	59.7	0.59	1.64 (p = 0.05)	H_0
C) friends or acquaintances played	5.3	1.3	1.69	1.64 (p = 0.05)	H_1
Question: Have your math teachers used digital mathematical games in math lessons?					
A) yes	17.1	32.5	2.07	1.64 (p = 0.05)	H_1
B) no	46.5	40.3	0.58	1.64 (p = 0.05)	H_0
C) I don't remember	36.4	27.3	1.04	1.64 (p = 0.05)	H_0
Question: Would you like computer math games to be used in school when learning mathematics?					
A) yes, it would be interesting	49.2	40.3	0.82	1.64 (p = 0.05)	H_0
B) yes, can try	41.2	35.1	0.62	1.64 (p = 0.05)	H_0
C) yes, I would replace all lessons with computer games	0.5	11.7	3.91	2.31 (p = 0.01)	H_1
D) no, it is inappropriate in mathematics lessons	9.1	13.1	0.82	1.64 (p = 0.05)	H_0

The statistical reliability of the differences in respondents' survey results presented in table 2 can be assessed using R. A. Fisher's angular transformation (table 2). According to the survey data and checking the statistical significance of their differences according to R. A. Fisher's angular transformation table 2), it can be argued that in the studied groups of respondents statistically more likely, with a probability of 95%, Ukrainian schoolchildren (5.3%) are familiar with digital math games because friends or acquaintances have played them, compared to Israeli schoolchildren (1.3%). It is also statistically significant more, with a probability of 95%, in schools where Israeli schoolchildren studied (32.5%), their mathematics teachers used digital math games in mathematics lessons, compared to Ukrainian schoolchildren (17.1%). Statistically significantly more with a probability of 91% 11.7% of Israeli schoolchildren, compared to 0.5% of schoolchildren from Ukraine, expressed a desire to replace using only digital games in all mathematics lessons. In other cases, no statistically significant difference with probabilities of

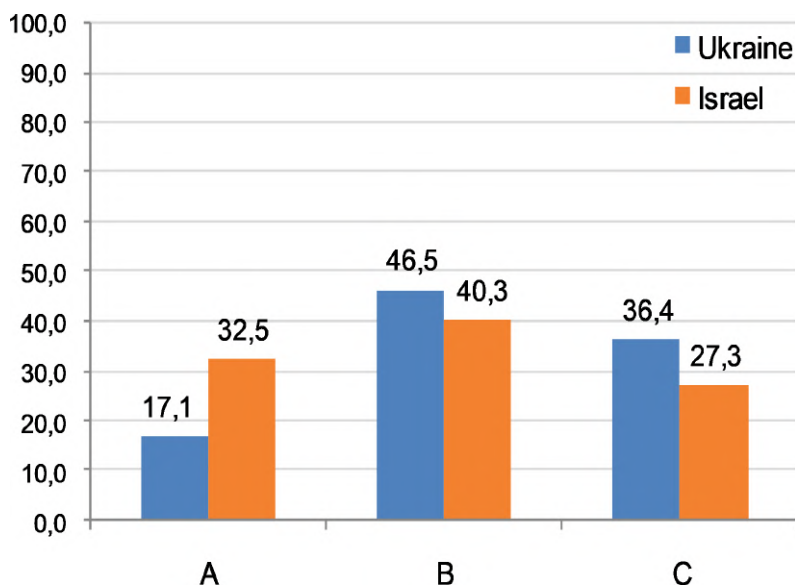


Figure 3. A bar chart showing the results of Ukrainian and Israeli schoolchildren’s answers to the question “Have your math teachers used digital mathematical games in math lessons?” (table 2).

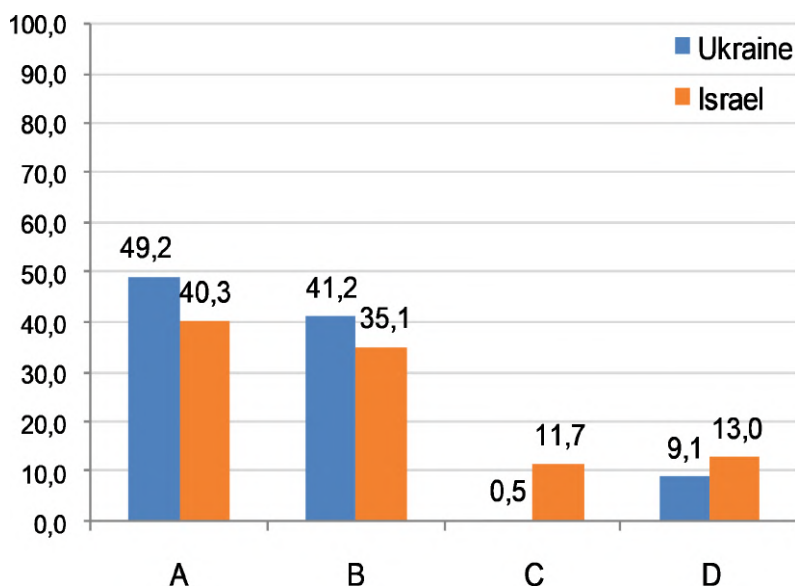


Figure 4. A bar chart showing the results of Ukrainian and Israeli schoolchildren’s answers to the question “Would you like computer math games to be used in school when learning mathematics?” (table 2).

95% or 99% was found in the studied groups of respondents.

The respondents’ answers to the question: “Would you like computer math games to be used in school” confirm that the majority of schoolchildren both in Ukraine and in Israel expressed an interest and desire for teachers to use mathematical digital games in mathematics lessons when learning mathematics?”. Analysis of the questionnaire revealed that “yes, it would be interesting” was the most common response chosen by the schoolchildren. (almost half of the

surveyed schoolchildren answered this way in Ukraine (49.2%), in Israel – 40.3%). The answer: “yes, can try” was also common (41.2% of Ukrainian schoolchildren and 35.1% of Israelis). It should be noted that in both countries almost the same share of schoolchildren (with a slight advantage in Israel of 13%) who believe that using digital games in mathematics lessons is inappropriate.

From the last two questions of table 2, additional information about the subject of the study was obtained. Here the answers had a more personal color. Schoolchildren could choose several answer options from those presented (table 2) and express their own opinion about the feasibility of using digital math games in the process of teaching mathematics. In particular, some students indicated the digital resources that their teachers used in the lessons, expressed their own wishes and their opinion about the survey.

3.2. Comparative analysis of the study of the opinion of schoolchildren in Ukraine and Israel regarding the feasibility of using digital mathematical games in the process of teaching mathematics

Delving into schoolchildren’s perspectives regarding the feasibility of using digital mathematical games, this study employs comparative analysis to assess the potential of digital mathematical games in the process of teaching mathematics. During the survey, questionnaire responses presented in table 3 and the data visualized in figure 5 were obtained.

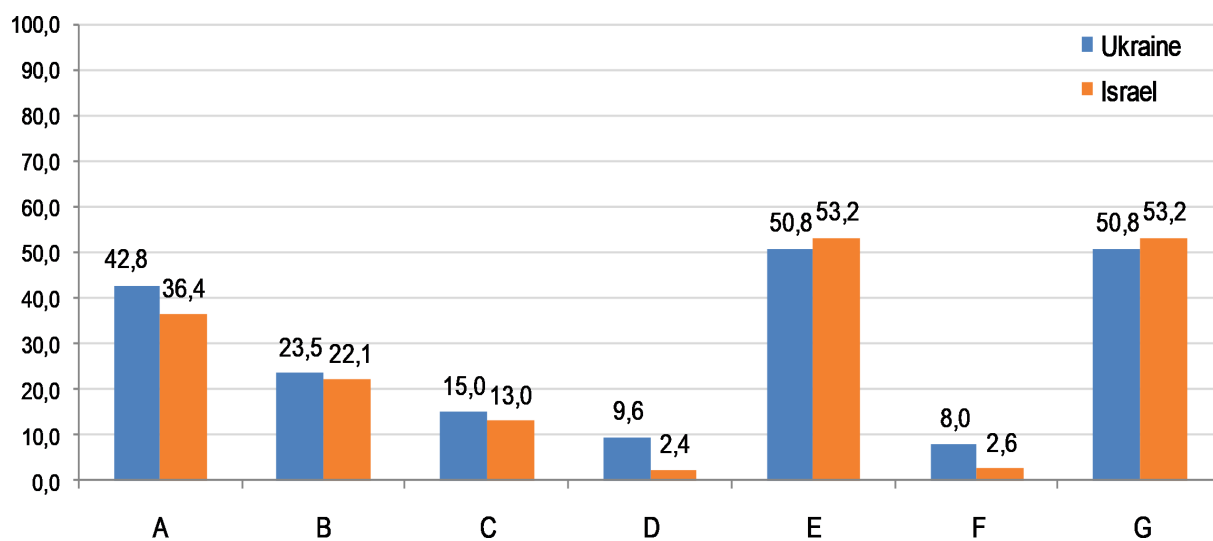


Figure 5. A bar chart showing the results of the responses of Ukrainian and Israeli schoolchildren regarding the feasibility of using mathematical digital games in the process of learning mathematics (table 3).

As a result of determining, using the ϕ^* -Fisher criterion, the statistical significance of the difference between the results of the survey of schoolchildren in Ukraine and Israel regarding the feasibility of using mathematical digital games in the teaching of mathematics, it was established that with a probability of 95%, more surveyed schoolchildren in Ukraine (9.6%), who are supporters of traditional teaching of mathematics, without the use of digital games, compared to 2.4% of the surveyed schoolchildren in Israel (table 3). It was also established that, with a probability of 95%, there are statistically significantly more surveyed schoolchildren in Ukraine (8.0%) who believe that digital games, even mathematical ones, are only entertainment for students and a waste of study time, compared to 2.6% of surveyed schoolchildren in Israel.

Table 3. The data of testing according to the ϕ^* -Fisher criterion of the statistical significance of the difference in the results of the survey of students of Ukraine and Israel regarding the feasibility of using mathematical digital games in the process of teaching mathematics.

Variants of answers	Answers of Ukrainian schoolchildren, %	Answers of Israeli schoolchildren, %	ϕ_{emp}^*	$\phi_{cr}^*, (p)$	The accepted hypothesis
Question: Choose the statements that apply to you.					
A) I know that there are cool mathematical digital games that give a good result in learning, but I have not heard that they are used in lessons	42.8	36.4	0.64	1.64 ($p = 0.05$)	H_0
B) I know examples of the use of digital mathematical games during the teaching of mathematics at school, while the children are satisfied	23.5	22.1	0.20	1.64 ($p = 0.05$)	H_0
C) I doubt that with the help of digital games you can get solid knowledge, skills and abilities in mathematics	15.0	13.0	0.37	1.64 ($p = 0.05$)	H_0
D) I am a supporter of traditional teaching of mathematics, without the use of digital games	9.6	2.4	2.22	1.64 ($p = 0.05$)	H_1
E) I admit that using mathematical digital games can be useful for learning mathematics	50.8	53.2	0.20	1.64 ($p = 0.05$)	H_0
F) I believe that digital games, even mathematical ones, are only entertainment for students and a waste of educational time	8.0	2.6	1.75	1.64 ($p = 0.05$)	H_0
G) I would be interested to learn more about mathematical digital games and try playing them	50.8	53.2	0.20	1.64 ($p = 0.05$)	H_1

In other cases, no statistically significant difference with probabilities of 95% or 99% was found in the studied answers of schoolchildren.

The largest choice among both Ukrainian and Israeli schoolchildren fell on the statement “I admit that using mathematical digital games can be useful for learning mathematics” and “I would be interested to learn more about mathematical digital games and try playing them”.

A slight difference in the data is observed when choosing the statements “I know that there are cool mathematical digital games that give a good result in learning, but I have not heard that they are used in lessons”, “I am a supporter of traditional teaching of mathematics, without the use of digital games” and “I believe that digital games, even mathematical ones, are only entertainment for students and a waste of educational time”. Traditional teaching methods are preferred more by Ukrainian schoolchildren (9.6%) in contrast to Israeli schoolchildren (2.4%).

As already mentioned, only 17.1% of Ukrainian respondents answered that teachers used mathematical digital games in mathematics lessons, which is significantly less than the corresponding indicator among Israeli schoolchildren (32.5%). Students were also surveyed to determine whether their teachers utilized digital mathematical games in their lessons, and if so, to identify the specific games employed. The most common answers among Ukrainian schoolchildren were: “I don’t remember”, “Matific”, “Kahoot”. One respondent answered that the teacher uses “Minecraft” in the geometry lesson. Israeli schoolchildren also noted that teachers used “Matific”, “Kahoot”, “Ten Fingers”, “mathPlayground”.

The survey further included open-ended questions, prompting students to share their vision for incorporating digital mountains into mathematics lessons. The answers to the open questions both among Ukrainian and among Israeli schoolchildren were quite diverse. Thus, the majority of respondents from both countries believe that digital games are appropriate in mathematics lessons: “if students sometimes play such games, they will have a greater desire to learn mathematics”, “I want digital games at school . It will make the lessons more interesting, maybe the children will start to learn better”, “Digital games in math lessons is a very good idea”, “I would like to use math digital games in math lessons, they are interesting and also educational”, “I think learning with digital games will be better”. Some students express more cautious judgments: “Sometimes they should be used to consider the application of mathematical theories in practice”, “It also depends on how stable this game is, if we are talking about a browser game and we will play on our phones, then there is a chance that all this may not work, or there will be some errors in the game that will not allow you to play normally. And if it’s on the screen in the classroom, or if we go to the computer science class and play on computers, then it would be possible to try it,” “Looking at which games. There are interesting and educational ones, and there are entertaining ones”, “You could try, but everything will depend on the level of educational material provided in the game, as well as on the format of the game itself”. There was also a small number of respondents who noted that “it is inappropriate in mathematics lessons”, “I am not a fan of digital math games”.

The field of digital gamification in education is constantly developing in accordance with the development of digital technologies. Therefore, the issue of using digital games in mathematics school education is relevant even at the present time. The main problems in the development and implementation of digital games in mathematics lessons at school remain the following: motivation and involvement; effectiveness of training; with technical support; systematic improvement of educational programs; integration with the curriculum; evaluation of training; professional training of teachers; the risk of computer addiction; and others.

Here are some of the problems of using digital computer games in mathematics education in more detail: There is an urgent need to develop clear predictable learning outcomes using computer games that would meet the standards of national curricula. Currently, there is a need to develop courses for teachers that would help master the basics of the GBL (game-based learning) concept, introduce various gaming software for teaching mathematics, and provide information about the principles and processes of learning based on computer games. In the course of surveys, some teachers commented on “problems in classroom management” caused

by playing in the classroom using gadgets. In their opinion, “control over the class can be lost.” Also, problems caused by the use of digital games in lessons can be “deviation from the purpose of the lesson”, “losing the priority of mathematics and understanding the lesson only as a time to play”. There are some problems related to the lack of the necessary technical infrastructure for the use of computer games.

To solve these issues, Vinnytsia Mykhailo Kotsiubynskyi State Pedagogical University is introducing new courses and introducing new topics into the curricula for future informatics teachers. These topics are mainly related to the issues of their preparation for the use of computer games in the process of learning mathematics at school. In particular, the subject “Development of didactic computer games”, “Development of VR/AR educational tools” is included in the curriculum of the discipline “Computer-oriented technologies for teaching informatics and mathematics”.

Also, at present, the authors are working on the development of methodological recommendations for future mathematics teachers. In which, in particular, issues of selection of digital mathematical games are considered, organization of work on them, since control over the class during mathematics lessons depends on this.

Despite these disadvantages, computer math games can be a valuable tool for teaching mathematics if used correctly. It is important that teachers are aware of potential problems and take steps to mitigate them. According to the authors, games should be used as a supplement to traditional teaching methods, not to replace them.

4. Discussion and conclusion

According to the results of the study on the opinion of school students regarding the expediency and possibilities of using digital mathematical games in the process of learning mathematics, as well as the comparative analysis of the obtained results of the study conducted in Ukraine and Israel, the following main conclusions were made:

The results of research conducted by us over many previous years on the issue of the use of digital games in school education [29, 32, 37], in particular, digital mathematical games, as well as the results of this study, indicate that the fascination of modern children with digital games can be used to increase educational achievements of students. This approach as a whole is designed to facilitate the effective implementation of the educational process, in particular, in mathematics. A number of researchers express a similar position [11, 12, 16–18, 20]. Studies conducted in primary and secondary schools on the use of educational digital games have shown good educational results. Prior studies primarily focused on teacher opinions [26, 29, 32, 33, 37], with limited consideration given to parental viewpoints [39]. This study delves into student interest for the use of digital mathematical games in the process of learning mathematics at school.

In general, students in both Ukraine (90.9%) and Israel (86.9%) are interested in learning mathematics using digital games. However, a significant percentage of surveyed Ukrainian students (82.9% of respondents) did not have the opportunity to actively use computer didactic games in mathematics lessons. Since they answered the question “Have your math teachers used digital mathematical games in math lessons?” “no” or “I don’t remember”. While these are the answers of 76.6% of Israeli schoolchildren. However, this difference is not significant. The observed difference in views between Ukrainian and Israeli schoolchildren regarding digital mathematical games might be attributed to the surveyed Israeli teachers’ increased integration of these games into their curriculum, accordingly, Israeli schoolchildren had the opportunity to play similar games in the process of learning mathematics.

Also, a part of Ukrainian students who have certain doubts about the feasibility of using computer mathematical games in the process of teaching mathematics (they doubted that with the help of computer games it is possible to acquire the necessary knowledge, skills, and abilities

in mathematics, were supporters of traditional education and believed that that the use of computer games to study mathematics is only entertainment for students and a waste of learning time is 32.6%, while among Israeli schoolchildren this indicator is 18%).

It was found out which digital mathematical games are the most popular in the process of teaching mathematics to students in schools in these countries, in particular, “Matific”, “Kahoot”, “Ten Fingers”, “mathPlayground”.

It should be noted that nowadays the introduction of digital games into the process of learning mathematics causes many debatable issues related to various aspects, in particular: determining the goals, place and limits of the use of digital mathematical games in the educational process; the readiness of mathematics teachers for methodically balanced use of computer games in the learning process, for conscious selection of software products. The search for answers to unsolved questions regarding the use of digital mathematical games in the educational process contributes to the digitalization of education, bringing it closer to global trends of sustainable development in this direction.

The authors see the directions for solving possible problems related to the use of digital games in mathematics lessons at school: the introduction of courses related to the use of digital computer games; development of methodological recommendations for future mathematics teachers and for mathematics teachers on the development and use of digital games; solving possible technical problems and others.

One of the directions of further research is the creation of appropriate methodological support for the involvement of international experience in the effective implementation of digital mathematical games in the process of teaching mathematics.

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Analytical and geometric interpretation of the flat arrangement of points by means of metric geometry in the study of metric spaces

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Analytical and geometric interpretation of the flat arrangement of points by means of metric geometry in the study of metric spaces

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Abstract. When studying metric spaces, students of higher education often have difficulties with understanding the basic concepts and properties of these spaces. This, to a large extent, is a consequence of the significant level of formalization of such concepts on the one hand, and the preservation of the corresponding formulations and names familiar to students from a school mathematics course. To overcome these difficulties, it is advisable to use methods of geometric interpretation and visualization of these properties. At the same time, it is appropriate to use elements of metric geometry. Its methods make it possible to interpret the geometric features of the mutual placement of points of metric space in Cartesian (rectangular) coordinate systems, which are familiar to students of higher education. Moreover, it becomes possible to visualize these features with the help of graphic editors, since they, as a rule, use numerical values of the coordinates of points to visualize them. Based on the definition of an angle as an ordered trio of points of an arbitrary metric space, and the angular characteristic of this angle, the fact of the flat placement of four points of a non-Euclidean metric space is established, and examples of digital visualization of this arrangement using the dynamic geometric environment GeoGebra 3D are given.

1. Introduction

The assimilation of basic concepts of metric spaces by students of higher education causes them certain difficulties, which are associated with a significant level of formalization of these concepts. In some cases, the geometric properties of non-Euclidean metric spaces can directly contradict the corresponding concepts and properties of classical Euclidean spaces. These contradictions, to a large extent, can be explained to the acquirers by constructing a geometric interpretation of a separate concept in a specific metric space. This paper proposes the use of elements of metric geometry to construct such interpretations. This makes it possible to make not only a graphic interpretation of a separate concept of a specific metric space, but also its visualization in classical Cartesian (rectangular) coordinate systems, using digital technologies.

Among the studies devoted to the issues of geometrization of metric spaces, one should single out the fundamental works [1–4], in which the main provisions and the latest research on metric geometry are outlined. Among domestic works devoted to various issues of geometrization of metric spaces, the following works can be noted: [5, 6]. The issues of geometric interpretation



and visualization of geometric properties of metric spaces in the course of higher mathematics were considered in works [7–10]. The issue of introducing elements of the theory of metric spaces into the school mathematics course and extracurricular work in mathematics was considered in works [11, 12].

The paper considers an example of flat placement of points in metric space. This flat placement is demonstrated using the dynamic geometry environment GeoGebra 3D.

The purpose of the article is to demonstrate the possibility of applying the elements of metric geometry to the construction of geometric interpretation and digital visualization of the main concepts of the theory of metric spaces, with the aim of improving their assimilation by students of higher education.

2. Preliminary information

At the beginning of the work, we will present some of the main definitions and facts of the theory of metric spaces. Basic of them are the concepts of space, points of space, distance between points of space.

Suppose that in the set X of elements x , according to a certain rule ρ , any two different elements x_1 and x_2 of this set can be matched with a single real number $\rho(x_1, x_2)$ so that the following conditions are met:

- 1) $\rho(x_1, x_2) > 0$;
- 2) $\rho(x_1, x_2) = \rho(x_2, x_1)$;

3) $\rho(x_1, x_2)\rho(x_1, x_3) + \rho(x_2, x_3)$, for any element x_3 of the set, then such a rule ρ is called the metric of the set X , the set itself is called the metric space with the metric ρ and denoted by (X, ρ) , the numerical value $\rho(x_1, x_2)$ is the distance between the elements x_1 and x_2 , and the elements themselves are points of the metric space. The method of setting the space metric determines its properties [13–15]. In the future, the distance between the points x_i and x_j will be briefly denoted by ρ_{ij} . The simplest examples of metric spaces are the one-dimensional (R^1), two-dimensional (R^2) and three-dimensional (R^3) Euclidean spaces, with which students of higher education are familiar from a school course in mathematics.

An example of a metric space is the space $C_{[0;1]}$ – the space of real functions continuous on the segment $[0;1]$. In this space, the distance between the functions $f(x)$ and $g(x)$ is given by the formula [16, 17]:

$$\rho(f, g) = \max_{x \in [0;1]} |f(x) - g(x)|. \quad (1)$$

If in condition 3) the inequality turns into equality, then it is said that the points x_1, x_2, x_3 are located in a straight line in the space are located in a straight line in the space X [18, 19]. A certain set of points of a metric space will be called rectilinearly placed in this space if any three of its points are rectilinearly placed. The definition of flat placement of points uses the concept of an angle formed by three points x_1, x_2, x_3 of the metric space (X, ρ) . An ordered triple of points (x_1, x_2, x_3) will be called an angle, in which the point x_2 is called the vertex of the angle, and the pairs of points (x_1, x_2) and (x_2, x_3) are the sides of the angle. To denote it, you can use the classic angle notation: $\angle(x_1, x_2, x_3)$ will be called the real number $\varphi(x_1, x_2, x_3)$, which is found according to the formula [20]:

$$\varphi(x_1, x_2, x_3) = \frac{\rho^2(x_1, x_2) + \rho^2(x_2, x_3) - \rho^2(x_1, x_3)}{2\rho(x_1, x_2)\rho(x_2, x_3)},$$

or shorter:

$$\varphi_{123} = \frac{\rho_{12}^2 + \rho_{23}^2 - \rho_{13}^2}{2\rho_{12}\rho_{23}}. \quad (2)$$

The definition of the flat arrangement of four different points of the metric space is based on the fact that the volume of the tetrahedron whose vertices are these points is equal to zero. Let

us say that four different points x_1, x_2, x_3, x_4 of the space (X, ρ) are flatly placement in this space, if the equality holds [10]:

$$\begin{vmatrix} 1 & \varphi_{213} & \varphi_{214} \\ \varphi_{213} & 1 & \varphi_{314} \\ \varphi_{214} & \varphi_{314} & 1 \end{vmatrix} = 1 + 2\varphi_{213}\varphi_{214}\varphi_{314} - \varphi_{213}^2 - \varphi_{214}^2 - \varphi_{314}^2 = 0. \tag{3}$$

A certain set of points of a metric space will be called flatly placement in this space if any four of its points are flatly placement in this space.

3. Main results

We will give an example of modeling the mutual placement of four different points of space $C_{[a;b]}$ using the dynamic geometric environment GeoGebra 3D. To do this, let's establish a certain orientation of the tetrahedron, the vertices of which are these points. We denote by $A(x_A, y_A, z_A), B(x_B, y_B, z_B), C(x_C, y_C, z_C), S(x_S, y_S, z_S)$ the vertices of the tetrahedron. We denote the lengths of the edges of the tetrahedron: $AB = a_1, AS = a_2, AC = a_3, BS = a_4, BC = a_5, CS = a_6$. We place vertex A in the center of the system of three-dimensional Cartesian (rectangular) coordinates (space R^3), and vertex B - on the positive half-axis of the abscissa (figure 1).

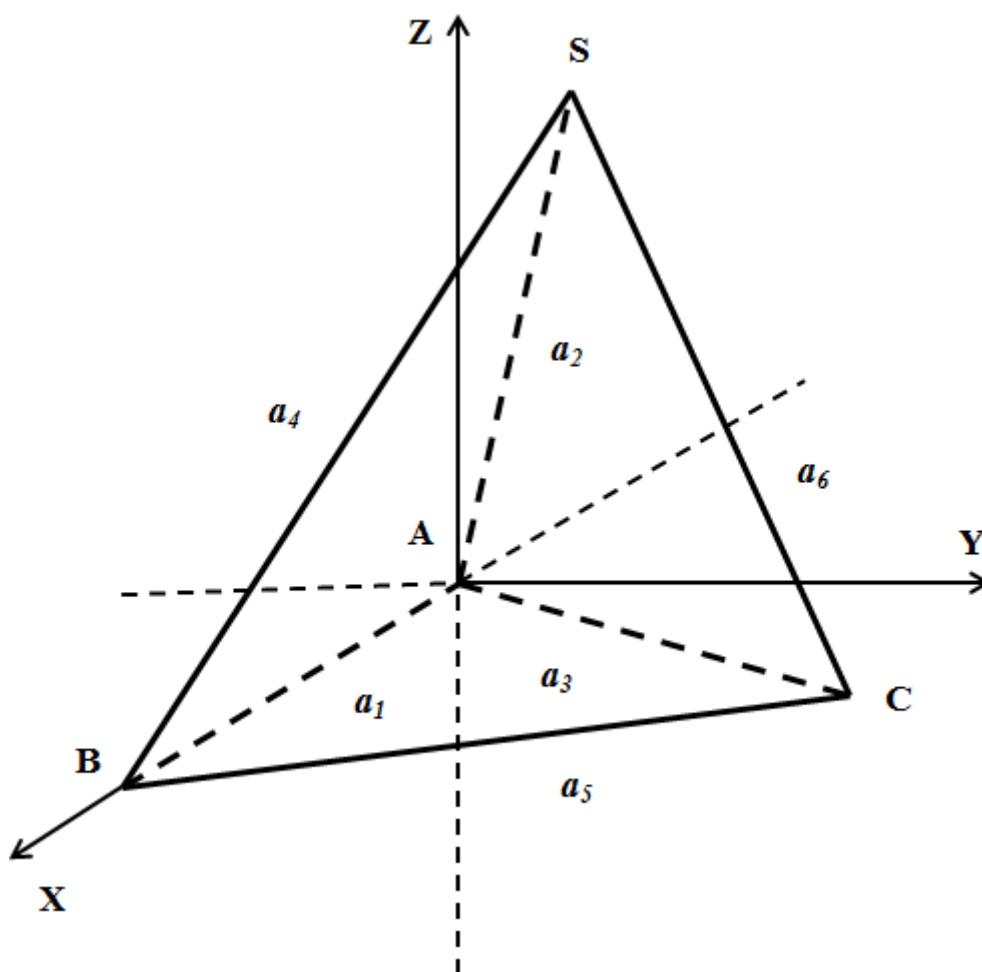


Figure 1. Orientation of the tetrahedron in the R^3 space.

When calculating the coordinates of the vertices of the tetrahedron, we will always choose the ordinate of point C and the applicate of point S as non-negative. The formulas for the coordinates of the vertices of the tetrahedron, with this orientation, will be:

$$\begin{aligned}
 x_A &= 0; y_A = 0; z_A = 0. \\
 x_B &= a_1; y_B = 0; z_B = 0. \\
 x_C &= \frac{1}{2a_1}(a_1^2 + a_3^2 - a_5^2); \\
 y_C &= \frac{1}{2a_1}\sqrt{2(a_1^2a_3^2 + a_1^2a_5^2 + a_3^2a_5^2) - a_1^4 - a_3^4 - a_5^4}; \\
 z_C &= 0. \\
 x_S &= \frac{1}{2a_1}(a_1^2 + a_2^2 - a_4^2); \\
 y_S &= \frac{2a_1^2a_2^2 + 2a_1^2a_3^2 - 2a_1^2a_6^2 - (a_1^2 + a_2^2 - a_4^2)(a_1^2 + a_3^2 - a_5^2)}{2a_1\sqrt{2(a_1^2a_3^2 + a_1^2a_5^2 + a_3^2a_5^2) - a_1^4 - a_3^4 - a_5^4}}; \\
 z_S &= \sqrt{\frac{a_1^2a_6^2(a_2^2 + a_3^2 + a_4^2 + a_5^2 - a_1^2 - a_6^2) + a_2^2a_5^2(a_1^2 + a_3^2 + a_4^2 + a_6^2 - a_2^2 - a_5^2) + a_3^2a_4^2(a_1^2 + a_2^2 + a_5^2 + a_6^2 - a_3^2 - a_4^2) - a_2^2a_3^2a_6^2 - a_1^2a_3^2a_5^2 - a_1^2a_2^2a_4^2 - a_4^2a_5^2a_6^2}{(a_1 + a_3 + a_5)(a_3 + a_5 - a_1)(a_1 + a_5 - a_3)(a_1 + a_3 - a_5)}}.
 \end{aligned}$$

This orientation of the tetrahedron is necessary, otherwise the task of constructing a tetrahedron with given edge lengths becomes indeterminate, since there can be 720 of all possible orientations. This can be demonstrated on the calculator, which calculates the value of the square of the volume of the tetrahedron using the Jungius formula. If this value is negative, then the tetrahedron does not exist with this orientation. If it is equal to zero, then all vertices of the tetrahedron lie in the same plane (are flatly placement). Consider an example of a flatly placement of points in the metric space $C_{[0;1]}$ (figure 2).

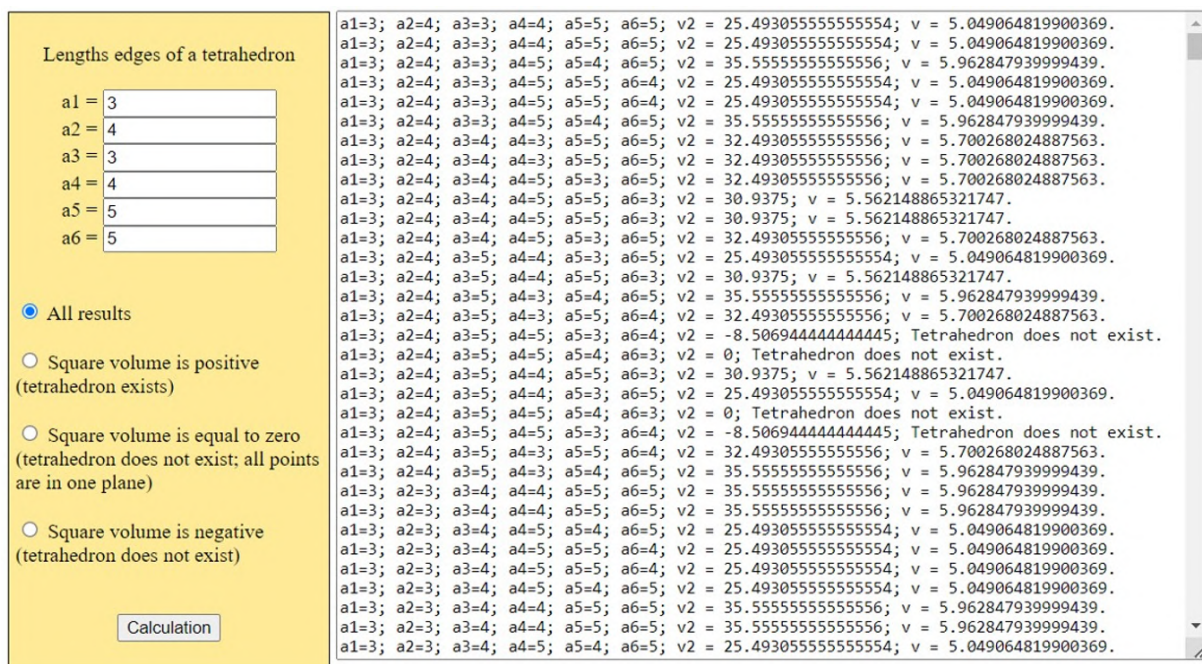


Figure 2. Existence of a tetrahedron with given edge lengths at different orientations.

Example 1. Let's take four points (functions) in the space $C_{[0;1]}$:

$$y_1 = x, y_2 = 0, y_3 = x - 1, y_4 = \frac{2\sqrt{3}}{3}(x - 0, 5).$$

Using formula (1), we will find the distances between these points:

$$\rho_{12} = \rho_{13} = \rho_{23} = 1, \rho_{14} = \rho_{24} = \rho_{34} = \frac{\sqrt{3}}{3}.$$

According to formula (2), we find the angular characteristics:

$$\varphi_{142} = \varphi_{143} = \varphi_{243} = -0,5.$$

Substituting these values into the left part of formula (3), we will have:

$$1 + 2(-0,5)(-0,5)(-0,5) - (-0,5)^2 - (-0,5)^2 - (-0,5)^2 = 0.$$

Thus, the points y_1, y_2, y_3, y_4 are flatly placed in the space $C_{[0;1]}$, and no three of these points are rectilinearly placed (there is no distance equal to the sum of the other two).

In Euclid's geometry, in the space R^3 , the image of point y_4 is the center of an equilateral triangle with vertices in the images of points y_1, y_2, y_3 . That is, the images of the points y_1, y_2, y_3, y_4 of the space $C_{[0;1]}$ are flatly placed in the space R^3 .

Modern digital technologies make it possible to visualize certain geometric properties of metric spaces. For example, with the help of the dynamic geometric environment GeoGebra 3D, you can visually make sure that the points y_1, y_2, y_3, y_4 of the space $C_{[0;1]}$, because their images in the space R^3 are flatly placed. To construct points in this environment, the values of their coordinates in the R^3 space are required, which are calculated according to the above formulas. After entering the length values $\rho_{12}, \rho_{13}, \rho_{14}, \rho_{23}, \rho_{24}, \rho_{34}$ from Example 1 into this application, with the appropriate orientation of the tetrahedron, we get the following image of the flatly placement of the points y_1, y_2, y_3, y_4 in the R^3 space (figure 3).

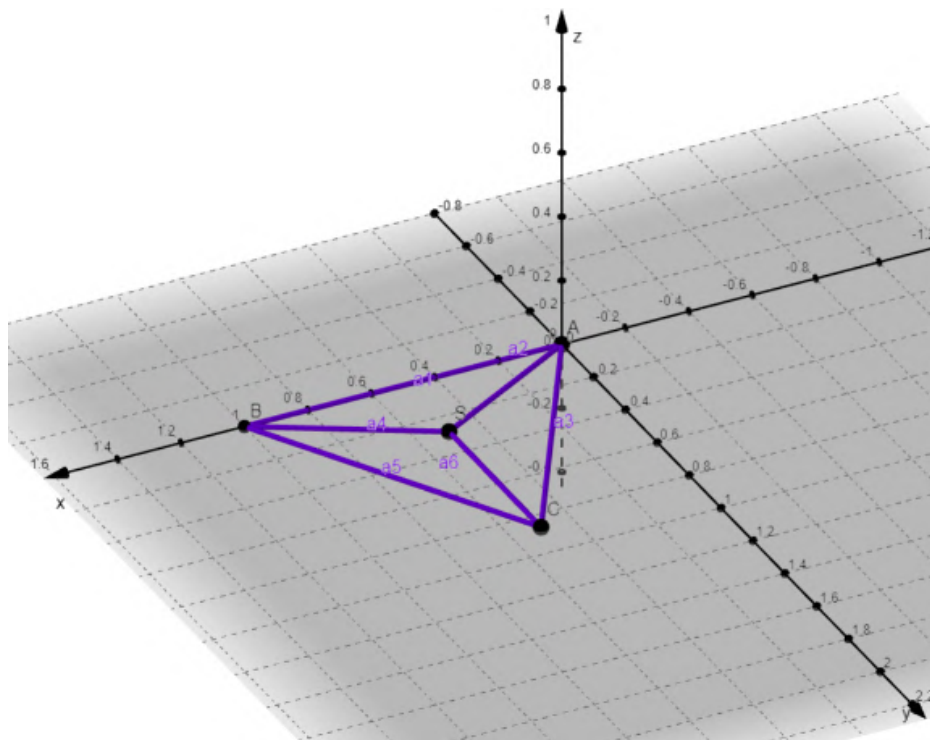


Figure 3. Interpretation of flat placement of points y_1, y_2, y_3, y_4 .

Figure 3 does not give a complete picture of the flat location of points y_1, y_2, y_3, y_4 , since it itself lies in a plane. In addition, the point from which the tetrahedron is visible (observation point) is located above the XOY plane. In order to make sure of their flat location, this image can be rotated to some angle in the GeoGebra 3D environment. In other words, you can change the observation point.

By rotating the image so that the viewing point lies in the XOY plane, you can make sure that all four points lie in this plane (figure 4).

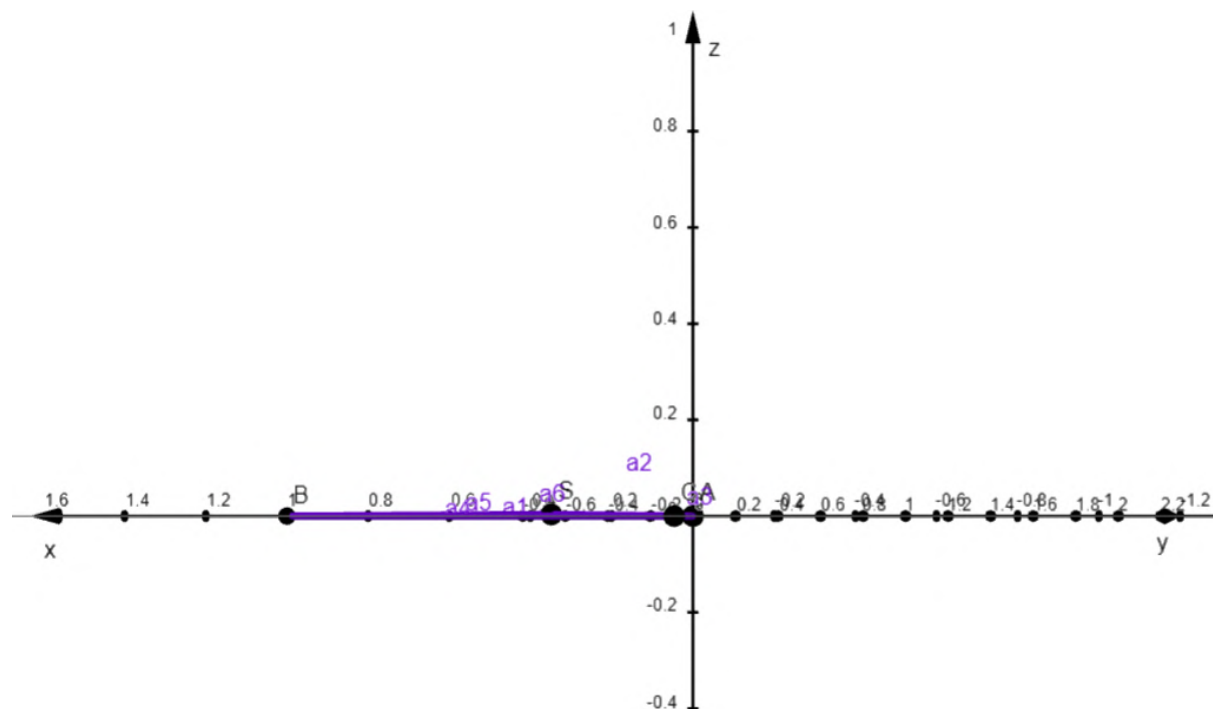


Figure 4. Interpretation of flat placement of points y_1, y_2, y_3, y_4 (view from the XOY plane point).

Digital technologies, in most cases, use approximate values of the coordinates of points, so the visualizations shown in Figures 3 and 4 are illustrative in nature, but sufficiently reflect the nature of mutual placement of points in space.

4. Conclusions

The material presented in this paper testifies to the possibility of using the elements of metric geometry when studying the theory of metric spaces by students of higher education. The analytical apparatus of metric geometry is sufficient for constructing geometric interpretations and digital visualizations of basic concepts and properties of non-Euclidean metric spaces. The use of elements of metric geometry makes it easier for students of higher education to understand those features of non-Euclidean metric spaces that are geometric in nature. The material of this work can be used in various types of non-formal education, introducing it to students of general secondary education who are studying in special classes with in-depth study of mathematics. Its use will make it possible to familiarize students with the simplest elements of non-Euclidean geometry.

The analytical apparatus of metric geometry makes it possible to form a generalized concept of a flat placement of points in an arbitrary metric space. The use of digital technologies,

in particular graphic editors, makes it possible to visualize individual features of the mutual placement of points in an arbitrary metric space.

Further research, in our opinion, should be aimed at building analytical and geometric interpretations of parallel and perpendicular placement of points of an arbitrary metric space. This will significantly expand the field of application of metric geometry in the study of metric spaces.

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The use of visualization technologies in the study of the probability of life on exoplanets

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Abstract. The modern generation receives a significant amount of information from various sources daily. The information received should be perceived and analyzed, and conclusions drawn. Young people prefer visual technologies that allow them to obtain and analyse dynamic details quickly. The educational process should not lag; on the contrary, it should prepare a thinking, creative person who can easily use modern digital technologies. This paper discusses the use of the Universal Sandbox 2 universe simulator in the study of astronomy, namely the search for exoplanets and the study of the conditions necessary for the existence of life on them.

1. Introduction

Today, the learning process should use modern digital and visual technologies. Using the latest technologies contributes to developing analytical and critical thinking [1, 2]. The contemporary generation receives information from various sources, which needs to be quickly analysed and critically evaluated. Another feature of today's youth is the visual perception of information. They are most attracted to the material presented in pictures, diagrams and charts. Astronomy is an observational science, but you can see and compare a limited number of objects in the Universe with your own eyes. When teaching astronomy, visualisation technologies are necessary, allowing you to understand basic astronomical concepts, the size and age of the Universe, and to see various astronomical phenomena. The importance of visualising new material is discussed in many modern works [3, 4], and the use of visualisation technologies in astronomy lessons is discussed in [5–9]. Ivanova et al. [10], Dawidziuk et al. [11], Bogomolova et al. [12] are consider visualisation technologies. There is an overview and systematisation of visualisation techniques [13–15] and types of digital visualisations and how best to use them [16].

Visualisation's main features and advantages are its simplicity, accessibility and high reading speed. It fulfils the following essential learning functions: informational, communicative, cognitive, entertaining, aesthetic and illustrative. The potential of visualisation in science teaching is quite significant. Teaching natural science subjects, especially physics and astronomy, in a modern school is the basis for the formation of a modern scientific worldview in students, understanding the importance of basic physical and astronomical concepts and laws for addressing the practical needs of society, developing students' intellectual abilities and cognitive interests. At the same time, most teachers note a decline in interest in studying physics and the ability to apply physics knowledge to analyse information about the environment and the Universe. Students are interested in astronomical phenomena, but their experience shows they



must use physical laws to understand and explain them. Accordingly, modern physics and astronomy teachers must increase motivation to study natural sciences, develop the ability to analyse information, draw independent, scientifically sound conclusions from the information received and make their own decisions. It is a creative, imaginative and thinking graduate with a formed scientific and natural worldview and developed digital competencies that society needs today.

A teacher can use various information visualisation technologies when teaching astronomy. The importance of visualisation technologies in helping increase students' cognitive activity is discussed in [17]. In addition to well-known forms, such as presentations, posters, animations, and videos, more interesting digital technologies allow for observing astronomical phenomena and influence them, such as interactive simulations and applications for mobile phones or computers [18]. Computer technology will enable students to perform design and technological tasks and develop creative learning projects. Modern computer technologies help to increase students' motivation and immersion in the game's reality and plot. They aim to form and combine theoretical knowledge and practical training of students.

2. Practical tasks for the topic Search for Life in the Universe

Information about discovering an Earth-type planet outside the Solar System constantly appears online. And, of course, the question immediately arises whether there could be life on a new exoplanet. To answer this question, we need to analyse the planet's and the star's physical parameters. The article proposes to combine visual digital technologies and practical tasks for studying exoplanets. Such an approach will help increase the motivation level to study astronomy and physics and develop students' physical and analytical thinking and mathematical, natural, and digital competencies. Many works suggest using the Universe Sandbox 2 simulation game as an interactive visualisation technology, which allows you to experiment in the Universe and create new star and planetary systems. It is possible to observe the development of existing and newly created stellar systems under the influence of gravitational forces at an accelerated pace [19].

One of the features of the Universe Sandbox 2 simulation is the study of exoplanets and the conditions necessary for life to exist on them. Students can analyse real planets in the life belt and how factors such as liquid water, magnetic fields, and atmospheres affect their likelihood of life. Exploring exoplanets was offered in astronomy classes to students majoring in 014 Secondary Education (Physics and Astronomy) and a female student to complete a scientific student work. The purpose of the practical task is to use the interactive simulator Universe Sandbox 2 to model and investigate systems for the possibility of life on planets belonging to these systems. Analyse the physical parameters of stars and planets that could affect the likelihood of life on the Earth under study. As a result of completing these activities, the students have become convinced that the presence of liquid water is an essential condition for the existence of life. Given what we know about life on Earth, we can identify the most critical factors and physical characteristics that affect the reality of life. One of the most important is water in a liquid state. If a planet orbits at a distance from its star such that liquid water can exist on its surface. It is said to be in the "habitable zone" – it is not too hot or cold and is likely to be suitable for life [20,21].

Atmospheric parameters can affect the temperature conditions on the planet's surface and the availability of oxygen and other elements necessary for life. It is also important to show students that astronomy continues to evolve and that there will be even more scientific advances.

The conditions for the existence of life on the planets and the search for it were investigated by the following scientists: in 1953 by Hubertus Strughold [22,23] and Harlow Shapley [24,25], and in 1959 by Su-Shu Huang [26–28]. Nowadays, NASA, the American Astronomical Society, ELSI (Earth Life Sciences Institute), etc., are involved in the study of the existence of life. Optimistic arguments often centred around the vastness of the Universe. There are roughly 100

billion stars in the Milky Way Galaxy (10^{11}) and approximately 100 billion other galaxies (10^{11}) in the observable Universe. So one can multiply the two for a crude estimate of the number of stars in the Universe – 10^{22} – a large number of places where planets could form.

The circumstellar habitable zone (CHZ) is a region around a star that is sufficiently distant to maintain an average temperature that allows water to exist in three states, primarily in liquid form. Liquid water is a critical factor in the potential formation of life on a planet and serves as a solvent in biochemistry. Therefore, it is believed that water plays a vital role in the formation of life on Earth. The CHZ is larger than the sphere surrounding the star, but it is often depicted in diagrams as a ring when viewed from above the plane of the star system. The CHZ is closely related to the inverse square law, which describes how energy decreases with distance from the star. As a result, the size and location of the CHZ change over time as the star evolves (figure 1). For the Sun, the current range of the CUZ is from 0.97 AU to 1.37 AU [20].

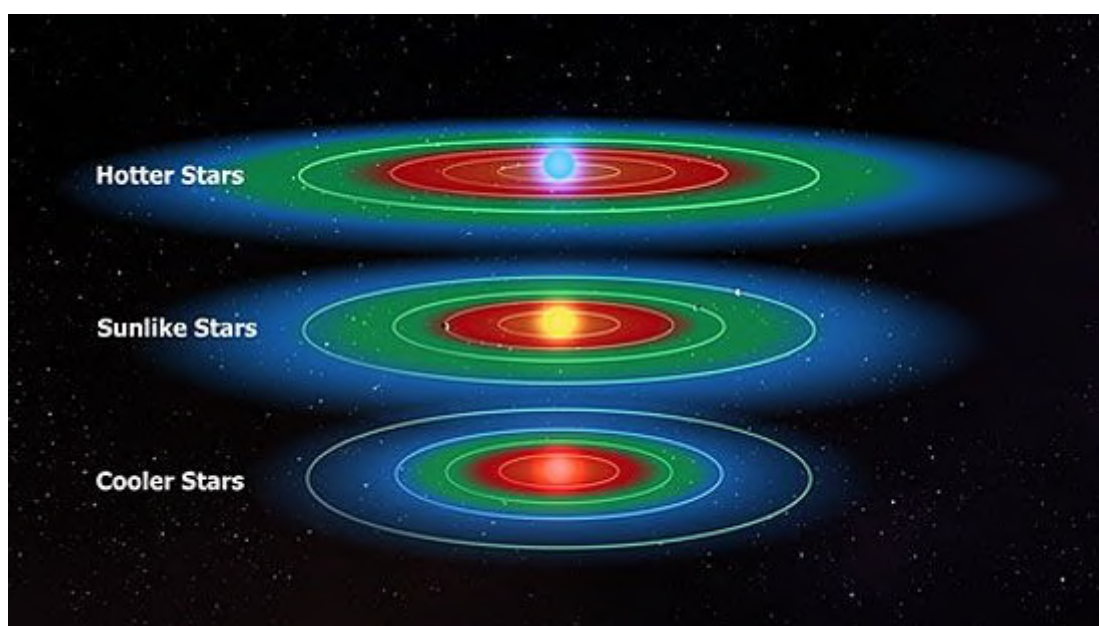


Figure 1. Dimensions of the habitable zone for stars of different mass and temperature.

The formula determines the size of the living area:

$$d_{AU} = L_{star} / L_{sun},$$

where

d_{AU} – its average radius in astronomical units.

L_{star} – luminosity of the star,

L_{sun} – the luminosity of the Sun.

There is a dependence on the location of the planet in this zone. The planets in the middle of the life zone will have more chances for life to emerge. If we take planets far from the middle part of the life zone, then life may not arise on these planets.

The habitable zone depends on the size of the star. If the star is small, this habitable zone will be close to the star and narrow. For giant stars, it will be far from the star and broader. The size of the habitable zone determines the probability of planets falling into it. If this zone is narrow, the chances are reduced. And with a broader size, the probability is higher.

The habitable zone must have stable conditions. These conditions also depend on the star and possible changes in its activity. The atmosphere protects the planet from harmful radiation from

stars. The mass of a planet is an essential factor in determining its atmosphere. Massive planets have a stronger gravitational field, which holds more atmosphere. Gravity attracts atmospheric molecules to the planet, preventing them from evaporating into space. Thus, the greater the planet's mass, the denser its atmosphere. The magnetosphere protects the atmosphere from the solar wind, which can disperse it. These characteristics are necessary for liquid water to exist on the planet's surface, a prerequisite for life.

3. Results of practical work in Universe Sandbox 2

Universe Sandbox 2 is a simulation program based on physical phenomena that allows you to reproduce simulations of the interaction of space objects [29]. The programme has a variety of functionalities that will enable researching and modelling such phenomena as the creation of systems, the formation of galaxies, and the interaction of space objects. It can change the parameters of cosmic bodies, such as mass, gravity, velocity, chemical composition and temperature. This affects the study of the interaction of these factors and their significance in creating certain conditions for studying various properties of space bodies. The application helps study space objects if students change the parameters from the initial ones. There is a function that, based on specific physical characteristics (radius, density, velocity and surface temperature), measures the percentage of similarity of an exoplanet to the Earth. It also measures the probability of life on planets in percentage terms based on a comparison of the Earth's properties necessary for life as we know it. The program determines the size of the habitable zone based on the luminosity of the star, measured from the surface of the star, not from its centre, so the radius of the star also affects the size of the habitable zone; if an object is selected, the size of the habitable zone depends on the albedo and infrared radiation of the object itself. The habitable zone is displayed in green; the inner part is marked in red, corresponding to a high temperature in this area, and the outer part is shown in blue, indicating temperatures too low for life to exist (figure 1).

Thus, the interactive simulator Universe Sanbox 2 was used to visualise the study of exoplanets and the likelihood of life on them. The students were asked to study the size of one of the most important factors for life – the habitable zone of a star. Detailed instructions for working with the programme and other interactive practical tasks can be found in the literature [29]. The size of the habitable zone depends on the star's mass (as the mass increases, the luminosity of the star increases, and, accordingly, its temperature and size). We need to take a given space and rulers scale for the study. The first step is to study the parameters of the solar system under normal conditions and at the mass of the Sun ($M = 1 \text{ Sun}$). In this case, the inhabited zone equals 76 conventional units. The next step is to change the mass and measure the size of the habitable zone. The results are shown in table 1 and figure 2,

Table 1. Analysis of the size of the habitable zone for a Sun-type star.

Figure	The mass of the star, the Sun	The size of the populated area, units	Luminosity, L_{sun}
Figure 2a	1	76	1
Figure 2b	1.05	79	1.35
Figure 2c	1.15	94	2.36
Figure 2d	0.9	55	0.544
Figure 2e	0.8	44	0.293
Figure 2f	1.3	–	–

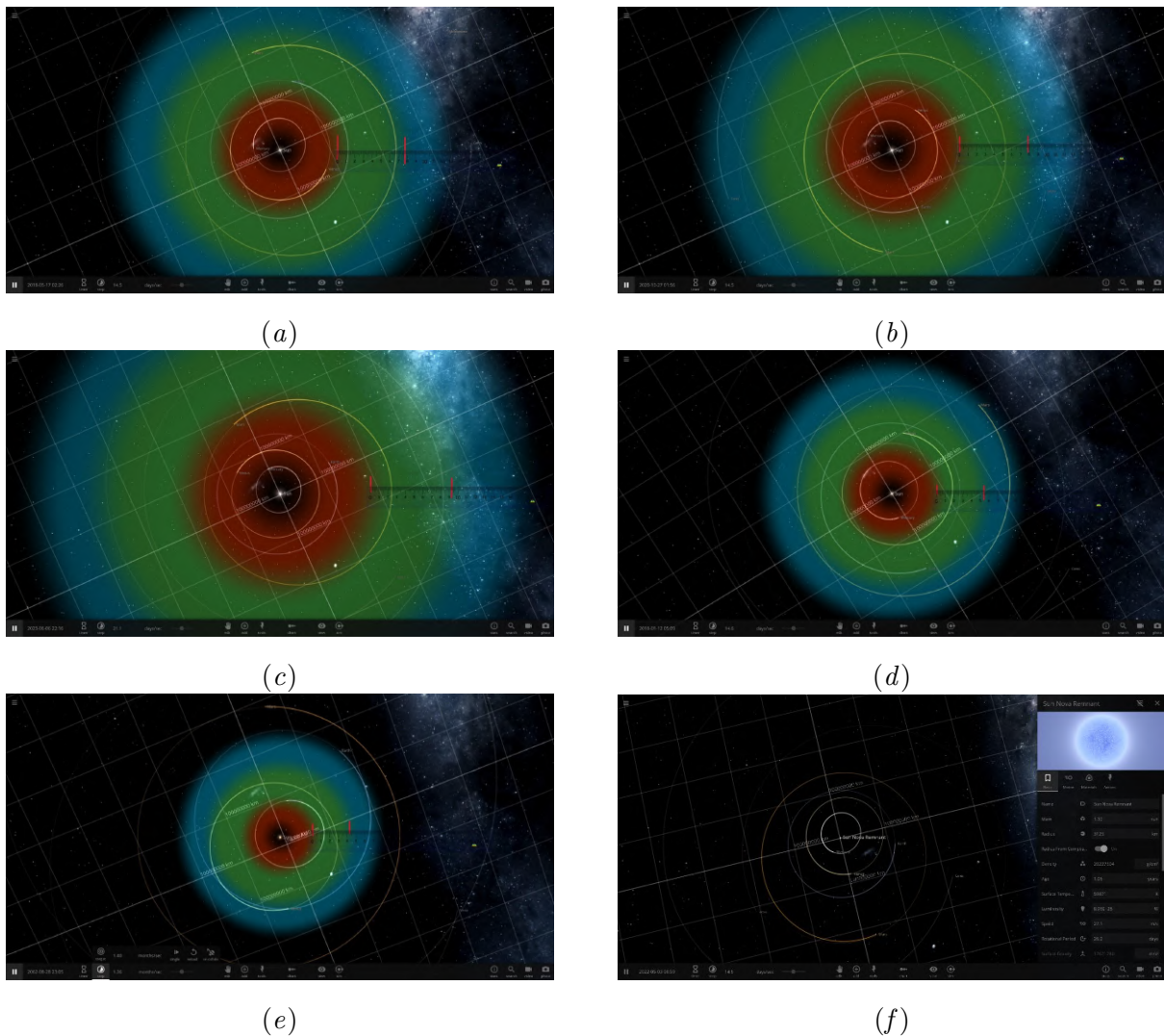


Figure 2. Habitable zone at the star with Sun mass (a), with mass of 1.05 Sun (b), with mass of 1.15 Sun (c), with mass of 0.9 Sun (d), with mass of 0.8 Sun (e), with mass of 1.3 Sun (f).

As can be seen from the table and figures, with increasing stellar mass, the habitable zone increases, and with decreasing mass, the habitable zone decreases. That is, the size of the habitable zone is directly proportional to the mass of the Sun (figure 3). The same conclusions are obtained for the star’s luminosity.

Note that at a mass of 1.30 Sun, the habitable zone disappears (figure 2f). This is because the luminosity and temperature of a star also depend on its mass. Accordingly, the temperature on the surface of the Sun is 5775 K, and with an increase in mass by 0.30 Sun, the temperature increased to 59871 K. For life to exist around the star, the star’s temperature must be between 4000 K and 7000 K. That is why the habitable zone is absent at a mass of 1.30 Sun.

The app allows you to check the conditions under which the Earth is in the habitable zone. Only at a sun mass of 1.05 suns is the planet still in the HZ; in all other cases, the Earth is in the red or blue zone, where life can no longer exist.

Observations were also made for another star, Kepler-186 [30, 31]. The results are shown in table 2 and on the graph (figure 5).

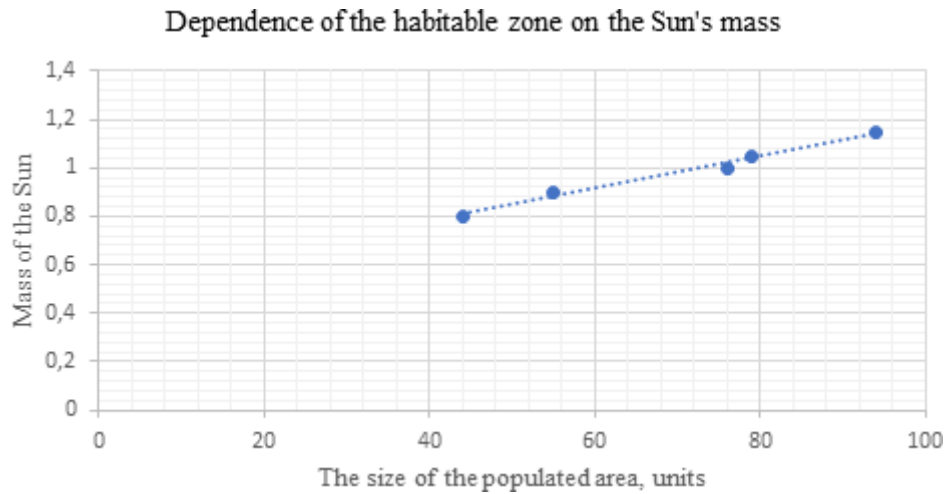


Figure 3. Graph of HZ dependence on the star’s mass.

Table 2. Analysis of the size of the habitable zone for the Kepler-186 star.

Figure	The mass of the star, the Sun	The size of the populated area, units
Figure 4a	0.478	17
Figure 4b	0.3	11
Figure 4c	0.2	9
Figure 4d	0.8	32
Figure 4e	1	54

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The app allows you to check the conditions under which the Earth is in the habitable zone. Only at a sun mass of 1.05 suns is the planet still in the HZ; in all other cases, the Earth is in the red or blue zone, where life can no longer exist.

The graph (figure 5) shows that the mass of a star is directly proportional to the habitable zone. Also, the example of Kepler-186 clearly shows how the orbits of planets change with mass. For instance, in figure 4d, we can see how the planet has left the orbit; in figure 4e, we can see how the star “swallowed” the planet. Therefore, the habitable zone and the planet’s location in orbit depend on the star’s mass.

The second task in the proposed practical work is to analyse the existence of life conditions on planets. To complete this useful task, you must change the physical characteristics of various exoplanets in stars’ life belts. These tasks were also performed using the Universe Sandbox 2 software.

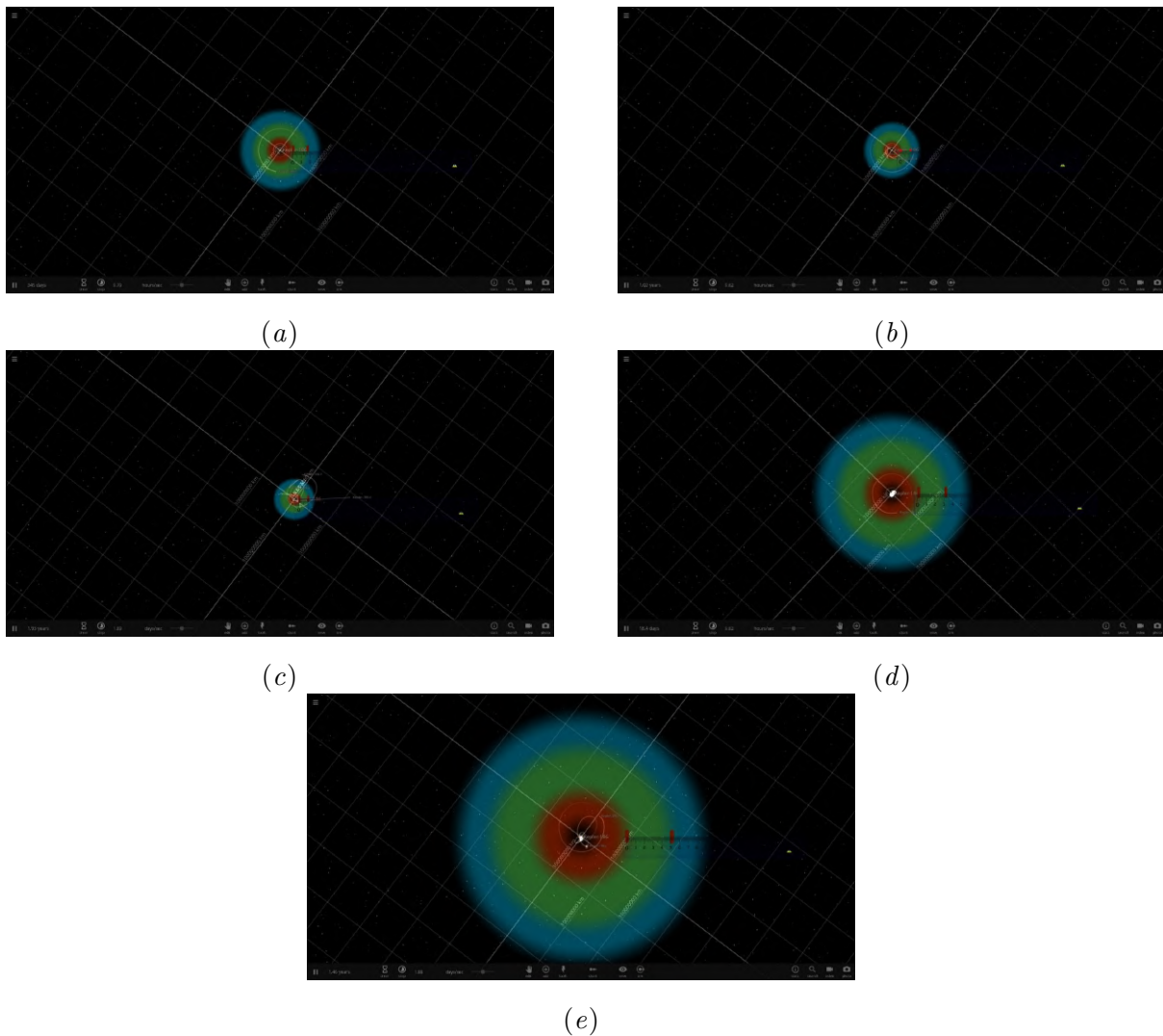


Figure 4. Habitable zone at the star of 0.478 Sun (a), with mass of 0.3 Sun (b), with mass of 0.9 Sun (c), with mass of 0.8 Sun (d), with mass of 1 Sun (e).

The planetary systems proposed for the study are Kepler-1229, Kepler-62, TRAPPIST-1, Gliese-667, and K2-18. These planets orbit stars of the K-M spectral type and have a maximum life belt. At the beginning of the study, these planets were outside the habitable zone. The main task was to achieve the maximum probability of life on this planet by changing the parameters.

The following parameters were changed:

- Pressure
- Mass of the atmosphere
- Size of the magnetosphere
- Magnetic field's strength
- Albedo
- Chemical composition of the planet
- Infrared radiation

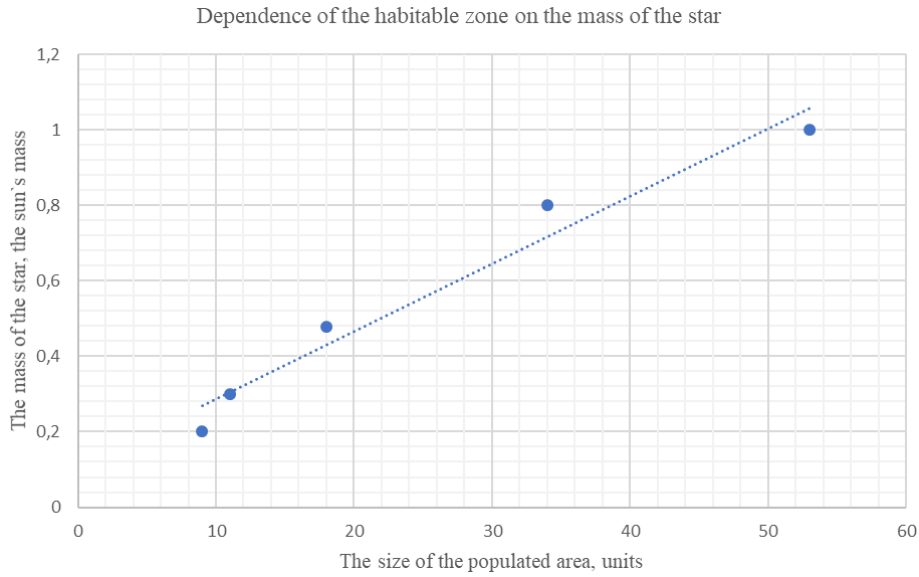


Figure 5. Graph of the HZ dependence on the mass of the Kepler-186 star.

- Atmospheric density
- Orbital eccentricity

The consequences of this were:

- Change in average temperature
- Changes in the planet’s radius
- The density of the planet
- Increasing the likeness to the Earth
- Increase the probability of life’s existence

The results are presented in tables 3-5.

Table 3. Results of exoplanet research 1.

Parameters of the planets	Kepler-1229b		Kepler-62c		Kepler-62e	
	To	After	To	After	To	After
Average temperature, °C	-66.8	8.68	293	53	-170	-4.5
Amount of water, $\times 10^{-5} M_{\oplus}$	0	2140	0	5.31	77.6	28.2
Mass of the planet, M_{\oplus}	2.91	2.93	0.134	0.134	4.5	4.50
Magnetic field, G	0	25	0	0.359	0	0.101
Pressure, kPa	0	101.33	67.3	102	610	85.1
Mass of the atmosphere, M_{\oplus}	0	1.39	0.513	0.716	7.59	0.98
Probability of life existence, %	0	45.5	0	32.1	0	58.5

For example, the Kepler-62 system is located at a distance of about 1200 light-years from Earth. The system consists of a K-class star and five planets. Three exoplanets are in the habitable zone: Kepler-62c, Kepler-62e, and Kepler-62f. These planets were discovered in 2013 year.

For example, the exoplanet Kepler-62c. Changes with this planet:

Table 4. Results of exoplanet research 2.

Parameters of the planets	EPIC-201912552b		Gliese-667Cf		Gliese-667Ce	
	To	After	To	After	To	After
Average temperature, °C	21.2	24.6	-32	21.5	-60	2.52
Amount of water, $\times 10^{-5} M_{\oplus}$	40000	460	0	10.8	14.4	28.3
Mass of the planet, M_{\oplus}	7.96	3.85	2.7	2.7	2.7	2.70
Magnetic field, G	0	0.201	0	0.0917	0	0.293
Pressure, kPa	530	72.2	0	99.0	427	156
Mass of the atmosphere, M_{\oplus}	13.7	1.03	0	1.18	5.51	2.02
Probability of life existence, %	0	80.7	0	42.1	0	34

Table 5. Results of exoplanet TRAPPIST research.

Parameters of the planets	1c		1d		1e		1f	
	To	After	To	After	To	After	To	After
Average temperature, °C	68.9	56.6	58	40	-15	11	-134	-45
Amount of water, $\times 10^{-5} M_{\oplus}$	0	11.9	1660	392	0	3.75	1300	179
Mass of the planet, $\times 10^{-3} M_{\oplus}$	1160	1160	297	297	772	772	934	934
Magnetic field, G $\times 10^{-3}$	0	350	0	167	0	74.8	0	53.4
Pressure, kPa	0	202	48.6	66.2	0	38.7	274	282
Mass of the atmosphere, M_{\oplus}	0	1.86	0.538	0.606	0	0.31	2.76	2.79
Probability of life existence, %.	0	30.1	10.24	36.8	0	13.5	10	34

1. The albedo was increased from 0.40 to 0.88, which changed the average temperature from 293°C to 101°C. The sea level has also changed from 0 km to 5 km.
2. Changes in the composition: Iron from 0.023 MM_{\oplus} to 0.0179 MM_{\oplus} . The silicate content has also changed from 0.114 M_{\oplus} to 0.116 M_{\oplus} . The planet's radius has also changed from 0.564 RM_{\oplus} to 0.552 RM_{\oplus} . The density has changed from 4115 kg/m^3 to 4396 kg/m^3 Sea level has also changed from 5 km to 6 km.
3. Change in the mass of the atmosphere from 0.503 M_{\oplus} to 0.716 M_{\oplus} . As a result, the pressure went from 67.3 kPa to 102 kPa. Atmospheric density from 6.406 kg/m^3 to 0.0946 kg/m^3 .
4. Repeated change of albedo from 0.88 to 0.93, which led to changes in the average temperature from 101° C to 53° C.

Results: Similarity to Earth from 48% to 77.9 %. Probability of life existence from 0% to 32.1%

Conclusions that can be drawn after completing such practical tasks:

1. Exoplanets with an Earth-like mass located in the life belt of their stars are the most likely candidates for habitability.
2. Exoplanets with strong magnetic fields may be more protected from harmful radiation from their stars.
3. Exoplanets with dense atmospheres may have more stable surface conditions than planets with rarefied atmospheres.



Figure 6. Exoplanet appearance before the study and after changing the parameters that increased the probability of life on the studied planets.

4. Conclusions

Universe Sandbox 2 is an interactive programme for modelling large space objects. It allows you to observe the effects of gravity on various objects in the Universe. You can also simulate planetary systems, galaxies and other objects by influencing gravity, time and other cosmic bodies. This application is used to implement interactive visualisation of practical astronomy tasks. In this paper, we propose studying exoplanets and the physical parameters under which life is possible. Namely, how the physical parameters of stars and planets affect the probability of life. The exoplanets studied were: Kepler-1229b, Kepler-62c, Kepler-62e, TRAPPIST-1c, TRAPPIST-1d, TRAPPIST-1e, TRAPPIST-1f, Gliese-667Ce, EPIC-201912552b. These planets were part of the habitable zone, but other physical parameters indicate that there are no conditions for life on these planets. Using the Universe Sandbox 2 simulation application, some physical parameters were changed, which led to an increase in the probability of life on the selected exoplanets. As a result, it was concluded that life may exist on other planets, but certain conditions must be met.

Based on the analysis of various sources of information, including the NASA Exoplanets website [32], we can conclude that to date, no exoplanets have been discovered near spectral class G stars, except for the Sun-Earth system, which would be in the habitable zone.

This type of task demonstrates the laws of gravity in the Universe in a playful way. Interactive simulations are an essential visualisation technology. Such technologies not only solve the problem of visualisation but also bring practical tasks to the school and bring them closer to fundamental scientific research. The additional possibility of using the application as a virtual reality helps to increase students' interest. As a result, students better understand the laws of gravity, methods of searching for exoplanets, physical parameters of stars and their exoplanets

that affect the likelihood of life on a found exoplanet.

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Enhancing student performance through laboratory-based instruction: A study on the relative density and buoyancy of liquids

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Enhancing student performance through laboratory-based instruction: A study on the relative density and buoyancy of liquids

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Abstract. This study investigates the effectiveness of laboratory-based instruction in conveying fundamental concepts related to the relative density and buoyancy of liquids within a secondary laboratory science program at a leading university in Mindanao. Despite the challenges posed by digital technology and remote learning, traditional laboratory experiments remain integral to science education, providing active, hands-on learning experiences. The primary focus is to assess the impact of laboratory instruction on student performance according to these principles. Our findings reveal a significant improvement in the performance of students in the experimental group. Notable enhancements were observed between pre-tests and post-tests, with statistical significance established at $\alpha = 0.05$. This underscores the substantial role of laboratory-based instruction in augmenting student performance. Additionally, when comparing final grades as an independent variable, we find that the laboratory teaching method significantly contributes to overall effectiveness in student learning. Furthermore, students' positive perceptions of the subject and their attitudes toward both the laboratory and the subject matter emerged as significant contributors to performance improvements. Consequently, this enhanced likelihood of achieving better grades in physics highlights the broader impact of laboratory-based instruction on student academic outcomes.

1. Introduction

In the ever-evolving landscape of educational methodologies, laboratory-based instruction remains an enduring and indispensable approach for imparting scientific concepts. Among these concepts, the principles of relative density and buoyancy of liquids stand as fundamental pillars in understanding the physical behaviour of materials. This instructional modality, rooted in hands-on experimentation, has proven to be a powerful catalyst for fostering a profound comprehension of these intricate scientific principles [1].

Science educators believed that laboratory experiments play a crucial role in science instruction. They provide essential training in observation, supply detailed information, and ignite students' interest which could enhance student's curiosity and eventually improves performance [2]. Laboratory teaching assumes that first-hand experience in observing and manipulating scientific materials is superior to other methods for developing understanding and appreciation. Laboratory-based instruction offers a unique platform for students to transcend theoretical knowledge and actively engage in the exploration of real-world phenomena.



Throughout the history of science curriculum, laboratory activities have held a distinctive and central role, enabling students to make sense of the natural world [3,4].

As students immerse themselves in carefully designed experiments, they not only witness the effects of varying liquid densities and buoyant forces but also develop a tactile understanding that goes beyond the limits of traditional classroom instruction [2,5].

This paper aims to explore the lasting impact of laboratory-based instruction in science laboratory subjects, with a specific focus on determining the factors that contribute to the effectiveness of the laboratory teaching method and its efficacy in enhancing student comprehension and skill acquisition related to the concepts of relative density and buoyancy of liquids.

2. Methodology

2.1. Design and instrument

This study employs a descriptive quasi-experimental research design, utilizing teacher-made test and questionnaire with 20 items, as data collection instrument. One hundred (100) heterogeneous students were used in this study and were group into control and experimental. They were asked to mark their answers by checking the provided choices.

2.2. Statistical tests

The paired T-test was used to test if there is a significant difference between the pre-test and the post test scores of the control and the experimental groups. The T-test for two independent samples was used to test if there is a significant difference between the pre-test scores of the control and experimental group and the post-test of the same groups.

Multiple regressions were also used to measure the influence of several predictable variables (independent variables) on the dependent variables (student grades). This analysis helps identify the factors that affect students' performance in both groups.

3. Results and discussions

The students in the Experimental Group demonstrated a remarkable level of academic proficiency both before and after the intervention. The marginal difference between their pre-test and post-test scores suggests that these students had a solid foundation of un in the subject matter from the outset. The post-test results further affirmed the sustainability of their high academic performance.

Table 1 shows the performance of the students in the pre-test and post-test of the experimental group. The highly significant t-value of 6.81 at $\alpha = 0.05$ indicates a substantial increase in post-test scores after implementing the intervention. These findings align with previous work by [1,5], indicating that laboratory-based instruction enhances student learning outcomes thus emphasizing the effectiveness of laboratory science in teaching and learning.

Table 1. Performance of the students in the experiment group.

	Average score	Difference	t-value	p-value
Pre-test	11.357	1.464	6.81	0.0000
Post-test	12.821			

Table 2 shows the performance of the students in the control group. The highly significant t-value of 5.32 at $\alpha = 0.05$ level of significance for the control group indicates a significant increase in the post-test scores. Despite not receiving the experimental intervention, students in

the control group demonstrated enhanced understanding positively attributed to supplementary lectures and discussions on the misconceptions of the topic [6]. Thus, the students even without having an activity, they were still able to cope up and correct their previous mistakes in the pre-test.

Table 2. Performance of the students in the control group.

	Average score	Difference	t-value	p-value
Pre-test	13.032	1.1935	5.32	0.0000
Post-test	14.226			

Table 3 shows the differences in the pre-test and post test scores of the students in the two groups. It can be seen in the table that the experimental group showed a larger increase in the post test than to the control group. This means that majority of the students in the experimental group got a higher score after the intervention was given. The students in the control group showed also an improvement in the test but lesser on the average compared to the experimental group. It can also be observed that the scores of the control group in both pre-test and post-test are higher on the average than the experimental group [7,8]. However, as seen the experimental group showed a larger improvement of 1.4643 in the score compared to 1.1935 by the control group.

Table 3. Difference in the post-test and pre-test scores of the control and experimental groups.

	Post-tests average score	Pre-test average score	Difference
Control group	14.226	13.032	1.1935
Experimental group	12.821	11.357	1.4643

Table 4 presents the pre-test and post-test performance of both the control group and the experimental group. This comparison of the pre-test and post-test scores within each group is essential for assessing the effectiveness of the laboratory-based instruction provided to the experimental group. As shown in the table 4, the control group has a positive shift of 1.194 while experimental group has a positive shift of 1.464 in the self-assessment after the intervention was implemented which is in agreeable with [1]. This indicates an improvement in performance after the interventions.

Table 4. Pre-test and post-test performance of the control and experimental group.

	N	Pre-test	SD	Post-test	SD
Control group	50	13.032	1.7553	14.226	2.0148
Experimental group	50	11.357	2.0380	12.821	1.8046

To compare the magnitude of change between experimental and control groups, we can calculate the difference between the positive shifts in the experimental and control groups:

$$\begin{aligned} \text{magnitude of change} &= \text{experimental group positive shift} - \text{control group positive shift} \\ \text{magnitude of change} &= 1.464 - 1.194 \\ \text{magnitude of change} &= 0.27 \end{aligned}$$

The magnitude of change between the experimental and control groups is approximately 0.27, which indicates that the experimental group experienced a slightly larger improvement in performance compared to the control group after the interventions. The experimental group received a targeted intervention. Perhaps this intervention was effective but not dramatically so, resulting in only a slight improvement [9].

Table 5 shows the mean gain scores of the control and experimental group. As shown in the table, the experimental group obtained a higher mean gain score of 1.4643 than that of the control group with 1.1935. This implies that the respondents in the experimental group have a better gain performance compared to the control group [10]. Moreover, the smaller standard deviation of the experimental group (1.2048) implies a better set of scores clustered close to the mean compared to the more dispersed set of scores in the control group with a standard deviation of 1.6164.

Table 5. Gain scores of the respondents in the control and experimental group.

	<i>N</i>	Difference in the post-test and pre-test scores of the control and experimental groups	SD
Control group	50	1.1935	1.6164
Experimental group	50	1.4643	1.2048

Table 6 shows the significant values on the difference between the pre-test and post-test performances of the control and experimental group. As shown, the computed t-value during the pre-test is 4.364 and it has a corresponding p-value of 0.000 which is less than the 5% level of significance. Thus, the null hypothesis is rejected. With this result, it is inferred that there is a significant difference between the performances of the control and experimental group during the pre-test. Additionally, the computed t-value and p-value during the post-test are 4.257 and 0.000 respectively. With a p-value which is less than the 5% level of significance, the null hypothesis is rejected. Thus, there is a significant difference between the post-test performances of the control and experimental group.

Table 6. Significant values on the difference between the pre-test and post-test performance of the control and experimental group.

	Group	Mean	SD	t-value	p-value	Decision	Interpretation
Pre-test	Control	13.032	1.7553	4.364	0.0000	Reject null hypothesis	There is a significant difference
	Experimental	11.357	2.0380				
Post-test	Control	14.226	2.0148	4.257	0.0000	Reject null hypothesis	There is a significant difference
	Experimental	12.821	1.8046				

Table 7 shows the significant values on the difference between the gain scores of the control and experimental group. As shown in the table, the computed t-value is 4.84 with a p-value of 0.000. With a p-value less than the 5% level of significance, the null hypothesis is rejected. Thus, there is a significant difference between the mean gain scores of the control and experimental. This further implies that the experimental group shows a significantly higher gain scores than that of the control group. It also infers that the method applied in the experimental group can significantly contribute in increasing students' performance compared to the method applied in the control group.

Table 7. Significant values on the difference between the gain scores of the control and experimental group.

Group	Mean	SD	t-value	p-value	Decision	Interpretation
Control	1.1935	1.6164	4.84	0.0000	Reject null hypothesis	There is a significant difference
Experimental	1.4643	1.2048				

In table 8, the result show that on the average, students in the control group performed better in the subject compared on the students in the experimental group (significant at $\alpha = 0.05$ level of significance). This is expected since students who belong to the first section are expected to perform well done to the students in the experimental group through the aid of the laboratory method is justified.

Table 8. Showing the final grades in physics of the students in the control and experimental group.

	Average score	Difference	t-value	p-value
Control group	90.258	1.579	2.28*	0.0267
Experimental group	88.6790			

Table 9 that follows shows that the grades of the students in the experimental group are related to their attitude towards physics and the used of the laboratory method to aid the course and thus improve performance [4,5]. As the students views the subject positively and participate well in the laboratory, he/she is more likely to have a better grade in physics. Provided that laboratory apparatus is always available and sufficient enough to make used of it, the students could have more idea on the activity that they were going to perform. As long as they are comfortable with the atmosphere that surrounds them in the laboratory room, it is possible that the activity contributes more information to the students understanding particularly in analysis.

Table 9. Linear regression for the grades of the students in the experimental group.

Predictor variable	Coefficient	Student's t	p-value
Constant	73.8562	18.77	0.0000
Difference	-6780	-1.68	0.1082
Attitude	3.4477	3.01	0.0068
Teacher's factor	0.3243	0.40	0.6909

Source	DF	SS	MS	F	p-value
Regression	3	42.1693	14.0564	4.21	0.0184
Residual	20	66.7890	3.3394		
Total	23	108.9580			

The F-value of 4.21 is significant at the level of significance, $\alpha = 0.05$, which means that there is a significant relationship between grades and the factors namely: (1) difference in the post-test

and pre-test scores, (2) attitudes of the students towards physics and the laboratory method, and (3) the teacher. Specifically, since the T-value for attitude is significant at $\alpha = 0.05$, the variable attitudes affect the grades of the students.

4. Conclusion

Laboratory-based instruction significantly improves to student's scores between pre-test and post-test assessments. Student's grades in the experimental group were positively correlated with their attitudes towards physics and the use of laboratory. Favourable attitudes and active participation in laboratory activities contribute to better grades. Ensuring the availability of physics equipment, conducive laboratory environments and comfortable atmospheres enhances students understanding and skill acquisition in experimental work.

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Measurement of ascorbic acid samples' optical rotation via an improvised polarimeter for purity assessment

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Measurement of ascorbic acid samples' optical rotation via an improvised polarimeter for purity assessment

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Abstract. The polarization of light finds practical application in physics and chemistry through the optical activity phenomenon, where polarimeters play a crucial role. This research builds on the improvised polarimeter designed by Kvittingen and Sjursnes [1], implemented with relevant modifications, to measure optical rotations of over-the-counter ascorbic acid samples. The study aims to assess the purity of two brands of ascorbic acid through polarimetry, comparing the calculated specific rotation with the literature values and supplementing the characterization with melting point determination. The constructed polarimeter, assembled using Lego bricks, provides an affordable alternative for educational purposes, addressing the challenges observed in the accessibility of commercial polarimeters for classroom demonstrations. The methodology encompasses pre-experiment steps involving polarimeter construction, the experiment utilizing polarimetry and complementary melting point determination, and post-experiment analysis to determine specific rotation from the measured optical rotations. Results indicate that Brand X exhibited specific rotations close to theoretical values, inferring high purity. Conversely, Brand Y shows significant deviations, suggesting potential impurities. These conclusions are supported by melting point data. The comprehensive approach combining polarimetry and melting point determination enhances the reliability of purity assessments, showcasing the effectiveness of the improvised polarimeter in practical applications.

1. Introduction

Polarization, one of the fundamental concepts in physics, has been a cornerstone in understanding the wave nature of electromagnetic radiation. An electromagnetic (EM) wave consists of oscillating electric and magnetic fields at right angles to the direction of propagation [2, 3]. The concept of polarization in an EM wave refers to the direction of the electric field vector in the EM wave as it travels through a medium [3]. The EM waves are linearly polarized if the electric field oscillations at a particular region consistently follow a clearly defined line. The field oscillations and propagation direction establish a polarization plane, indicating that linear polarization denotes a wave polarized in a specific plane [3].

One application of polarization is found in organic chemistry through optical activity. Optical activity refers to a unique property exhibited by specific compounds where they can rotate plane-polarized light [4]. A compound that rotates the polarization plane is considered to be optically active. Otherwise, it is called optically inactive. Chiral compounds are optically active, while achiral compounds are inactive [5].



A technique called polarimetry measures the optical activity of chiral substances. It is applied to examine the chiral substances and determine their concentration in solutions for quality control, laboratory analytics, and research and development in different industries [6]. A polarimeter is an instrument used to measure the direction and angles of rotation of polarized light after passing through a compound. The polarimeter works because a plane-polarized light from the polarizer is passed through a sample of optically active substance, and rotation of the polarization plane happens. The rotation angle is determined using a second polarizer, the analyzer [7].

The optical rotation is usually expressed in the standard way, called specific rotation $[\alpha]_D$. Specific rotation is defined as the observed rotation when light with a 589.6 nm wavelength (corresponding to the D1-line emission of sodium lamp) is employed in conjunction with a sample path length l of 1 dm and a sample concentration c of 1 g/cm³. A 25°C temperature is also commonly used during optical rotation measurements [8]. The calculation of specific rotation for a sample is governed by Biot's law, which is expressed as [7]:

$$[\alpha]_D = \frac{\text{Observed rotation (degrees)}}{\text{Path length (dm)} \times \text{Concentration (g/cm}^3)} = \frac{\alpha}{l \times c} \quad (1)$$

When the observed optical rotation is expressed in a specific rotation, it yields a physical constant unique to a particular optically active compound. The unit of specific rotation, as defined in equation (1), is [(deg · cm²)/g], although it is commonly abbreviated to degrees [9] or presented without units altogether [7].

While the theory behind polarimeters is straightforward, Breton observed that undergraduate students often struggle to grasp the practical measurement of the angle of rotation of polarized light [10]. Although commercial polarimeters are available, their cost is high and unsuited for demonstrating chirality in a classroom environment [10]. With this, several basic, homemade polarimeters have been documented for use in demonstrations and student experiments. For instance, Mehta and Greenbowe introduced a cost-effective polarimeter made from a shoebox, recycled office supplies, and standard laboratory equipment [11]. Similarly, Breton presented a simple homemade polarimeter using two PVC pipes that serve as the “body” and the top piece of the polarimeter [10]. Furthermore, Bernard and Mendez devised a self-constructed polarimeter featuring a 3D-printed base [12].

The polarimeter design developed by Kvittingen and Sjursnes was chosen for adaptation and modification in this research due to its numerous advantages over other available designs. Notably, its resolution of 0.5° [1] surpasses that of alternative models. For instance, the overhead projector-based polarimeter, as described by Dorn et al., offers only an accuracy of ±5° [13], while the polarimeter featuring a 3D-printed body achieves a resolution of only 2.5° [12].

This polarimeter design stands out by requiring minimal skills for a more durable setup, distinguishing it from alternatives such as those utilizing shoe boxes [11] or PVC pipes [10]. Using Lego as the foundational material and the straightforward cutting involved in crafting the polarizers and plastic dial contributes to its ease of construction. In contrast, constructing polarimeters from PVC pipes requires a difficult material-cutting process. Similarly, shoebox-based designs may lack durability, mainly if they come into contact with solutions, compromising their structural integrity over time. Moreover, the affordability of the polarimeter design makes it suitable for educational settings, unlike polarimeters reliant on 3D-printing technology. Their design shares a similar layout with a classic polarimeter but is not a black-box system, allowing easy demonstration of the optical activity and polarization concepts.

Beyond the classroom, polarimetry finds applications in various scientific fields: biomedical engineering [14], pharmaceutical, food, and chemical industries [15]. In this study, the researchers aimed to characterize the purity of two different brands of ascorbic acid. This was achieved using an improvised polarimeter, adapted and modified from the design of Kvittingen

and Sjursnes [1], where the specific rotation of the samples was determined. The results were compared with existing literature, and supplementary characterization (e.g., melting point determination) was conducted for a comprehensive analysis.

2. Methodology

The methodology employed in this research is divided into three main subsections: the pre-experiment, involving polarimeter construction; the experiment proper, utilizing polarimetry and melting point determination as the primary and complementary characterizations, respectively; and the post-experiment, which includes analyzing polarimetry results and melting point data.

2.1. Pre-experiment

In constructing the polarimeter, the instructions laid out by Kvittingen and Sjursnes in their research's supporting documentation [1] were followed. This includes attachments for the patterns of a protractor, plastic dial, and fixed and rotating polarizing films.

The protractor pattern was printed on paper and then laminated (figure 1). The plastic dial pattern was printed and transferred onto a laminated laminating pouch (figure 2). Likewise, the patterns for the fixed and rotating polarizing films were printed on paper and transferred to the linear polarizing film (figure 3). Then, the rotating polarizing film was secured on the plastic dial with a few small pieces of tape (figure 4).

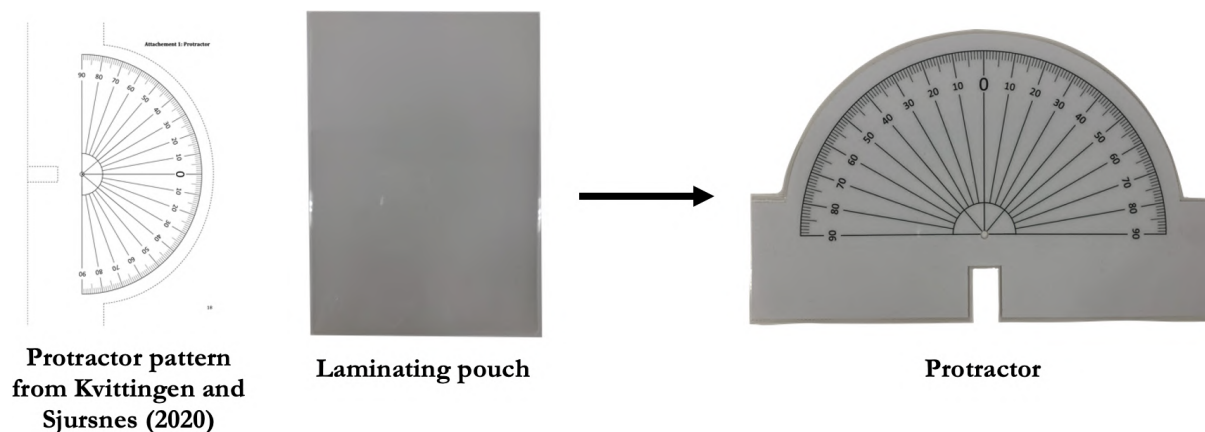


Figure 1. The protractor pattern was laminated in a laminating pouch.

The plastic dial and protractors were punctured with a puncher to connect them using a Lego connector peg and 2×1 Lego bricks, as shown in figure 5. After preparing the necessary parts of the instrument, they were assembled with the aid of Lego bricks as the foundation (figure 6). The four 6×16 Lego plates were connected and placed on a 48×48 base plate for the instrument's base. This is where the parts of the polarimeter were attached: the fixed polarizing film sandwiched between two pieces of Lego bricks, the LED light source held using a 2×1 brick with a hole mounted on a 2×2 yellow brick, the glass cuvette between the two polarizing films (fixed and rotating films), the protractor and the plastic dial where the rotating polarizing film was taped, and the detector LED placed behind the protractor.

The setup contains simple circuitry, as the LED light source is connected to three 1.5 V (4.5 V) batteries and a 50Ω -resistor. The LED light source's negative pole was connected to the battery's negative terminal (black wire), and the positive pole was connected to the positive terminal (red wire), as shown in figure 7 and figure 8. On the other hand, the LED detector was connected to a voltmeter with an internal resistance of $10M\Omega$ and in series with a $10M\Omega$ resistor (figure 9 and figure 10).

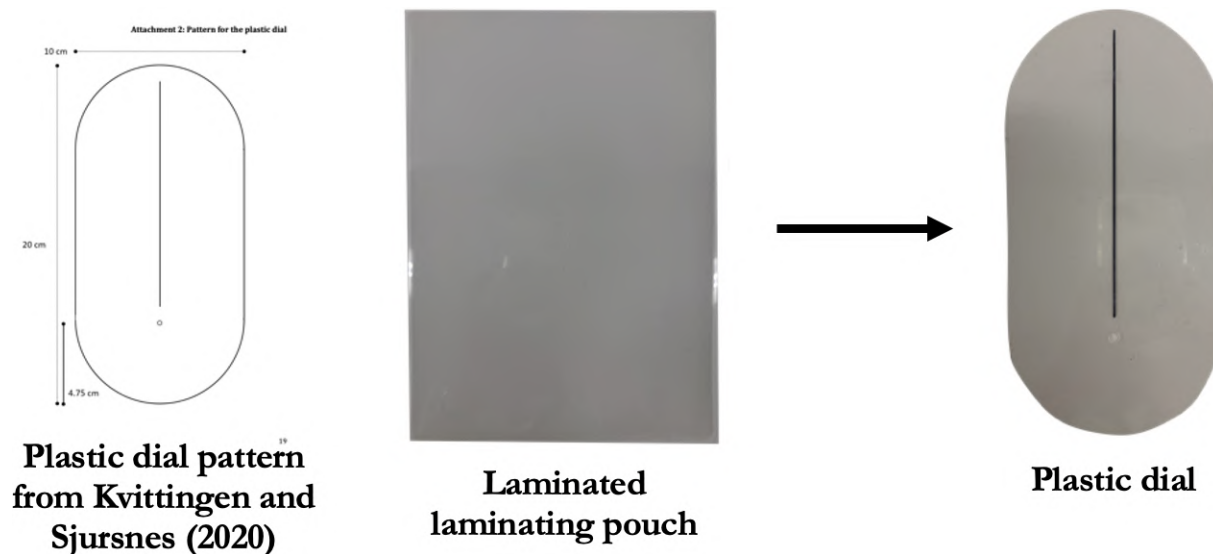


Figure 2. The plastic dial pattern was transferred to a laminated laminating pouch.

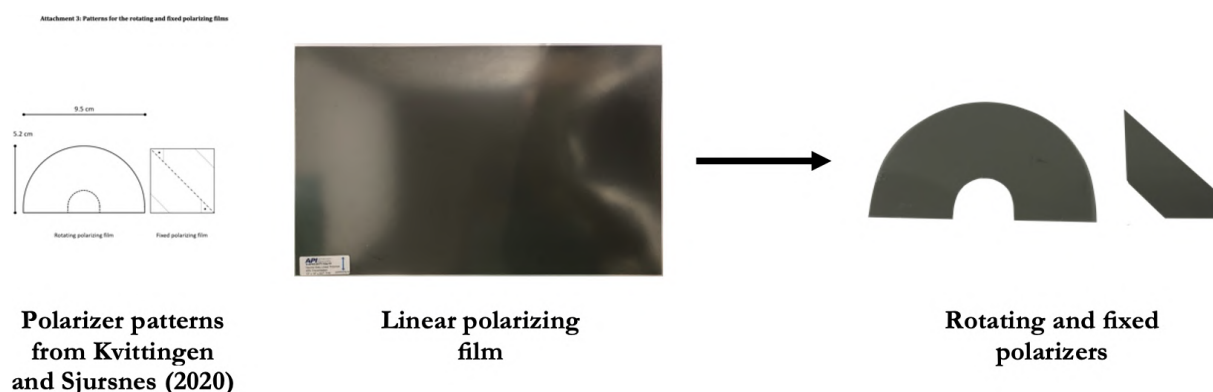


Figure 3. Rotating and fixed polarizing film patterns transferred onto the polarizing film.

It is important to note that the series resistor is the component added to the original polarimeter design. The resistor is incorporated for more accurate measurements as it stabilizes the voltage readings from the voltmeter and avoids large fluctuations. This is critical in determining the optical zero during light transmittance measurement. Large fluctuations in voltage readings can be prone to introducing errors in the optical rotation calculation, especially for substances with low specific rotations. For ascorbic acid with an average specific rotation of $+21^\circ$, the observed rotation for a given sample path length and concentration must be at least 1.0° . Otherwise, the percentage error will be substantial. However, with the added resistor, the voltage readings for each 0.5° step would be distinct, accurately determining the optical zero.

2.2. Experiment proper: Polarimetry

Two different brands of ascorbic acid, already in powder form, were utilized as different samples and then compared. A certain amount of powdered sample was dissolved in a particular volume of distilled water to obtain the desired sample concentration of 0.25 g/cm^3 . For instance, when 0.2 dm glass cuvette was used, 2.5 g of the sample was weighed through a digital balance and then transferred to a beaker. Then, 10 mL of the solvent (distilled water), measured using a

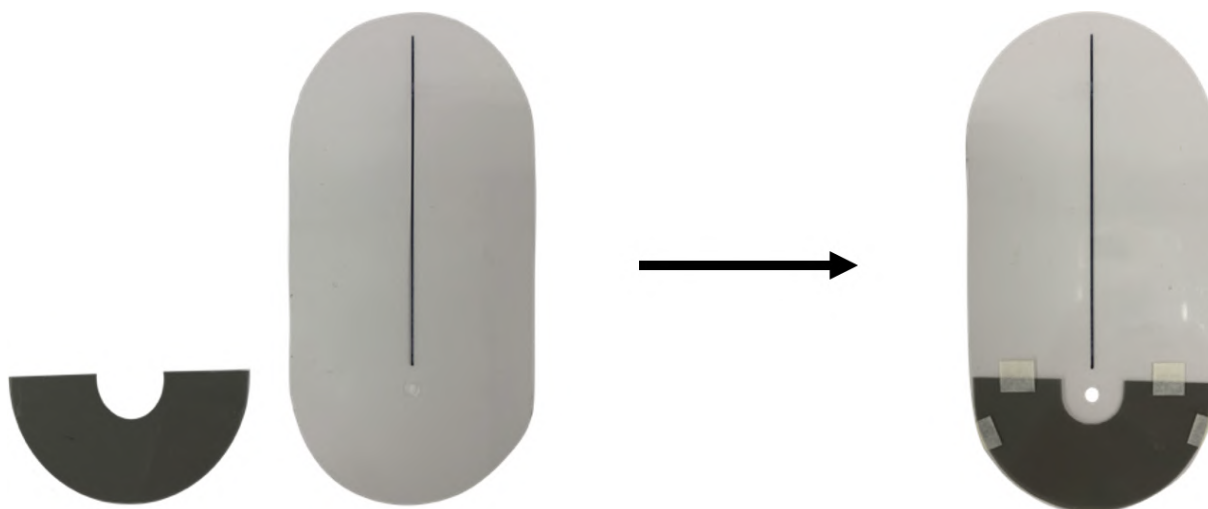


Figure 4. Rotating polarizing film secured onto the plastic dial.

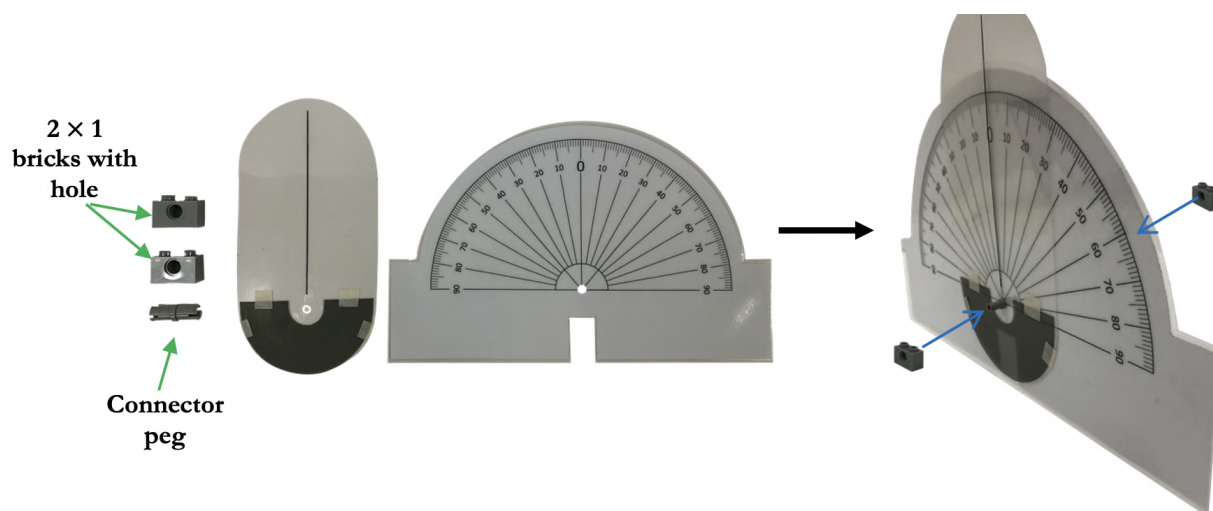


Figure 5. Connecting plastic dial and protractor using a connector peg and 2×1 bricks.

graduated cylinder, was used to dissolve the sample. The solution was mixed using a stirring rod and transferred to a glass cuvette of a particular path length l . To investigate the relationship between the observed optical rotation and the sample's path length, glass cuvettes of different path lengths l (0.2 dm, 0.4 dm, 0.6 dm, 0.8 dm, 1.0 dm) were used.

The instrument was first calibrated before measuring the optical rotation through the constructed polarimeter in a dark room. Theoretically, minimum light transmittance must be zero. However, since the precision in mounting the instrument varies, calibration was performed to determine the "optical zero". Two detection methods were performed to do this: visual detection and voltage detection.

The visual detection procedure was introduced in this study to serve as the baseline for voltage detection. In this process, white paper was substituted for the red LED detector to observe the transmitted polarized light. The angles corresponding to the dimmest light intensity were recorded. However, note that detection based on visual observation can be limited by the observer's subjective reading [12]. Thus, a 4.0° margin was added on either side of the noted

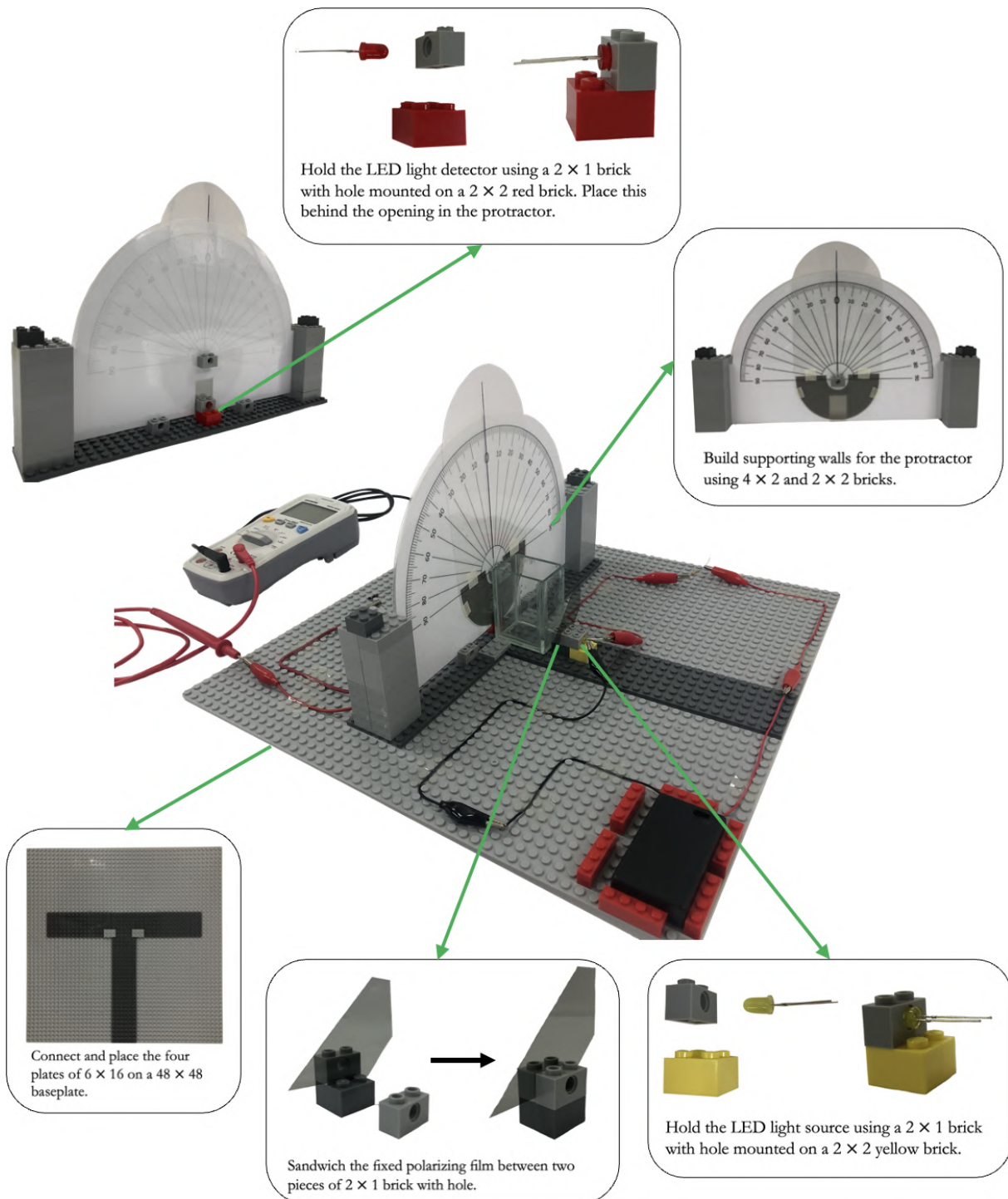


Figure 6. Assembly of the polarimeter.

angles to ensure precision. For instance, in visual detection, if the dimmest light fell within the range of angles from -4.0° to 4.0° , the investigation was extended to -8.0° to 8.0° in the subsequent voltage detection phase.

Note that observing the rotation facing the detector (figure 11) is opposite to the conventional rules for defining rotation of plane-polarized light as dextrorotatory (right, (+), d -) and

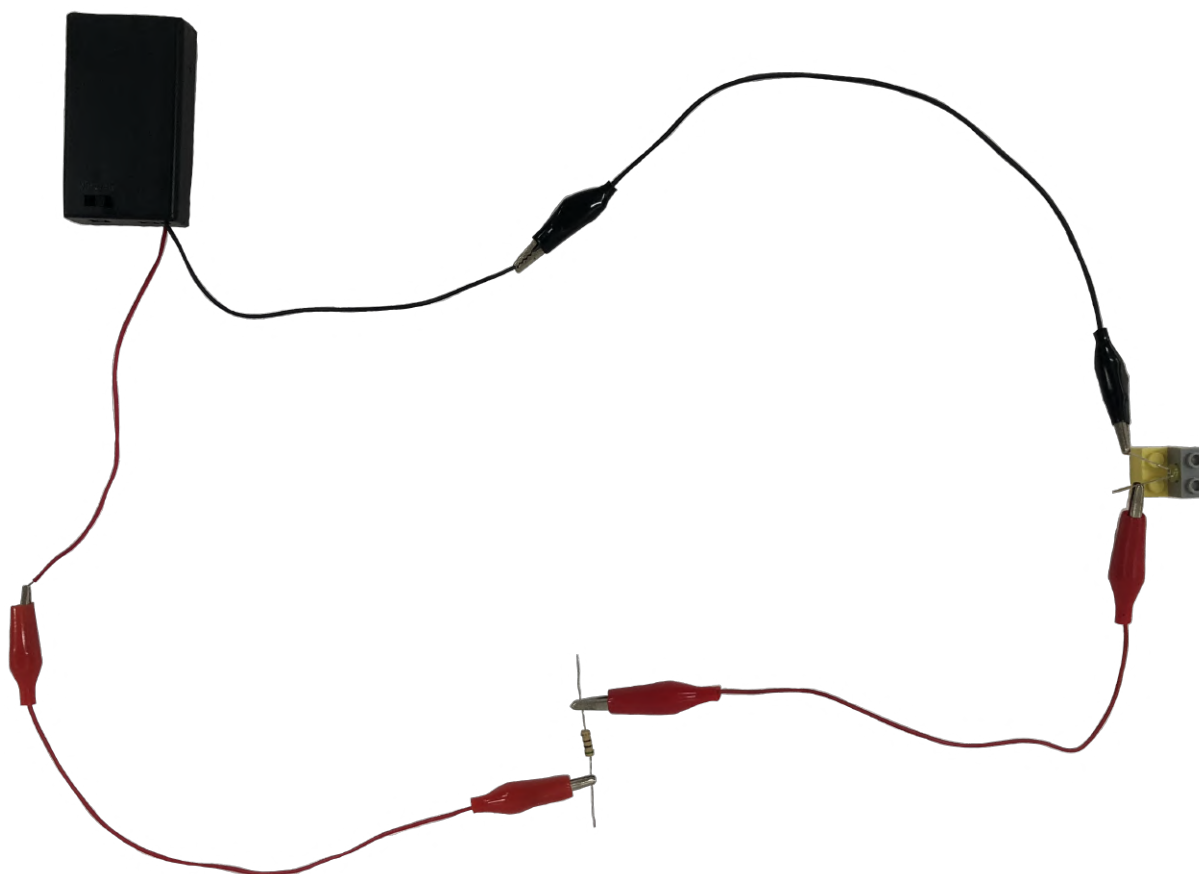


Figure 7. LED light source and battery connection.

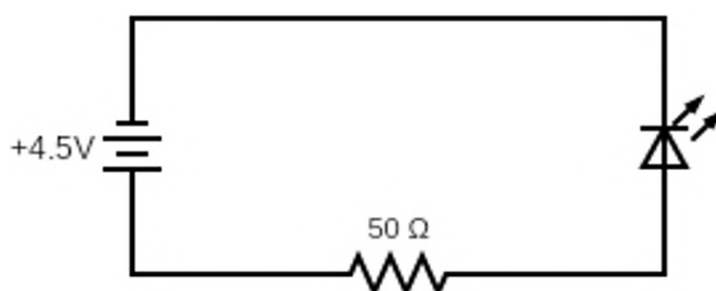


Figure 8. Circuit diagram of the LED light source and battery connection.

levorotatory (left, (-), l -). Therefore, as shown in figure 11, a conventionally levorotatory solution will rotate to the right and a conventionally dextrorotatory solution to the left.

During voltage detection, the voltage reading at the midpoint of the visually detected angle range was initially recorded. Subsequently, incremental adjustments of 0.5° were made to the dial on both sides while monitoring the voltage displayed on the multimeter. The lowest voltage reading observed denoted the point of minimum light transmittance. The angle corresponding to this minimum transmittance was identified as the “optical zero”.

Once the polarimeter was set and calibrated, the sample was poured into the glass cuvette, as shown in figure 12. Conceptually, the optical zero would vary since the plane of the polarized light will be rotated. To locate the “new optical zero” (i.e., the angle where the new minimum



Figure 9. LED detector with resistor and voltmeter.

light transmittance is) and determine if the rotation is to the left or right, the same method used for calibration was repeated. The dial was slowly adjusted in steps of 0.5° at each side of the midpoint of the visually detected angle range. Then, the observed optical rotation was calculated by subtracting the calibrated optical zero from the new one.

The implemented modifications in the circuitry and the enhancement in the detection of minimum light transmittance have yielded reliable measurement values. Despite the relatively low specific rotation of ascorbic acid, resulting in significantly lower observed optical rotations compared to the samples considered by the primary reference, such as the D-(+)-Sucrose (i.e., specific rotation of $[\alpha]_{592} = +66.8^\circ$ [1] and observed rotation of $\alpha = +13^\circ$ [1]), the constructed instrument has demonstrated precision and accuracy in measuring the observed rotation of the ascorbic acid samples.

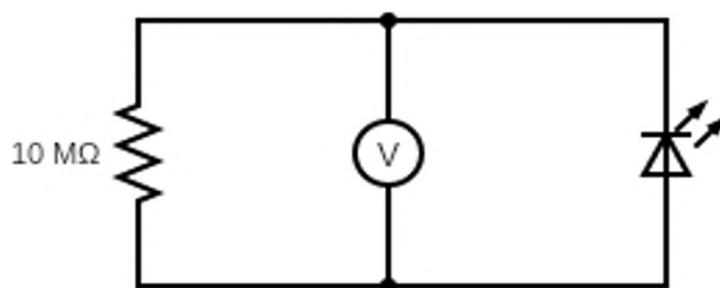


Figure 10. Circuit diagram of the LED detector with resistor and voltmeter.

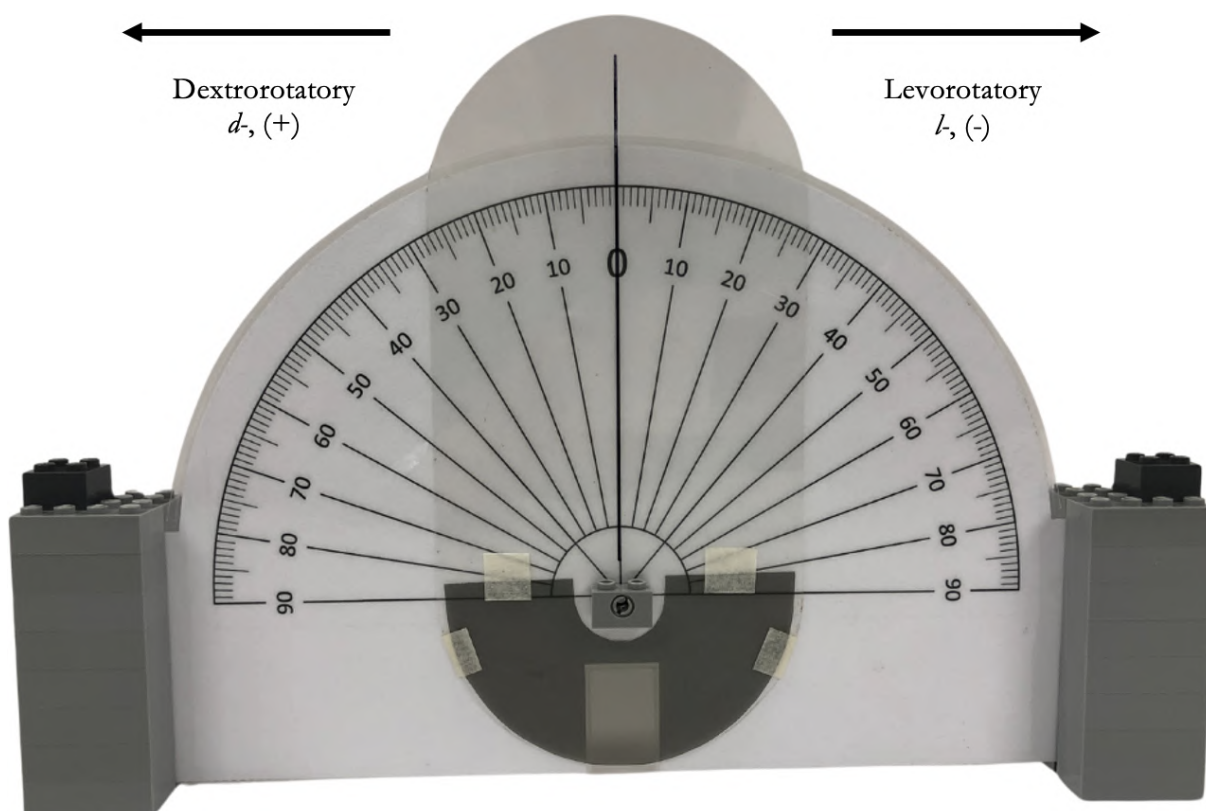


Figure 11. Observing rotation facing the LED detector: levorotatory solutions rotate polarized light to the right while dextrorotatory solutions rotate it to the left.

2.3. Experiment proper: Melting point determination

This analysis method served as the standard for determining the purity of the samples and supplemented the characterization using polarimetry. In this method, the melting points of the samples of different brands were determined using the *Mel-Temp* electrothermal melting point apparatus, which has a temperature resolution of $\pm 1^\circ\text{C}$ [16].

In preparing the sample suitable for the apparatus, a small amount was transferred into a watch glass and dried in an oven for about 10 minutes at 70°C using a *Yamato DX402* drying oven. While the oven-drying process was primarily employed to ensure complete drying, alternative methods can also be used, such as placing the sample on a piece of filter paper and folding the paper around it. This approach involves pressing the folded paper to absorb excess moisture and repeating the process until the paper remains dry [17].

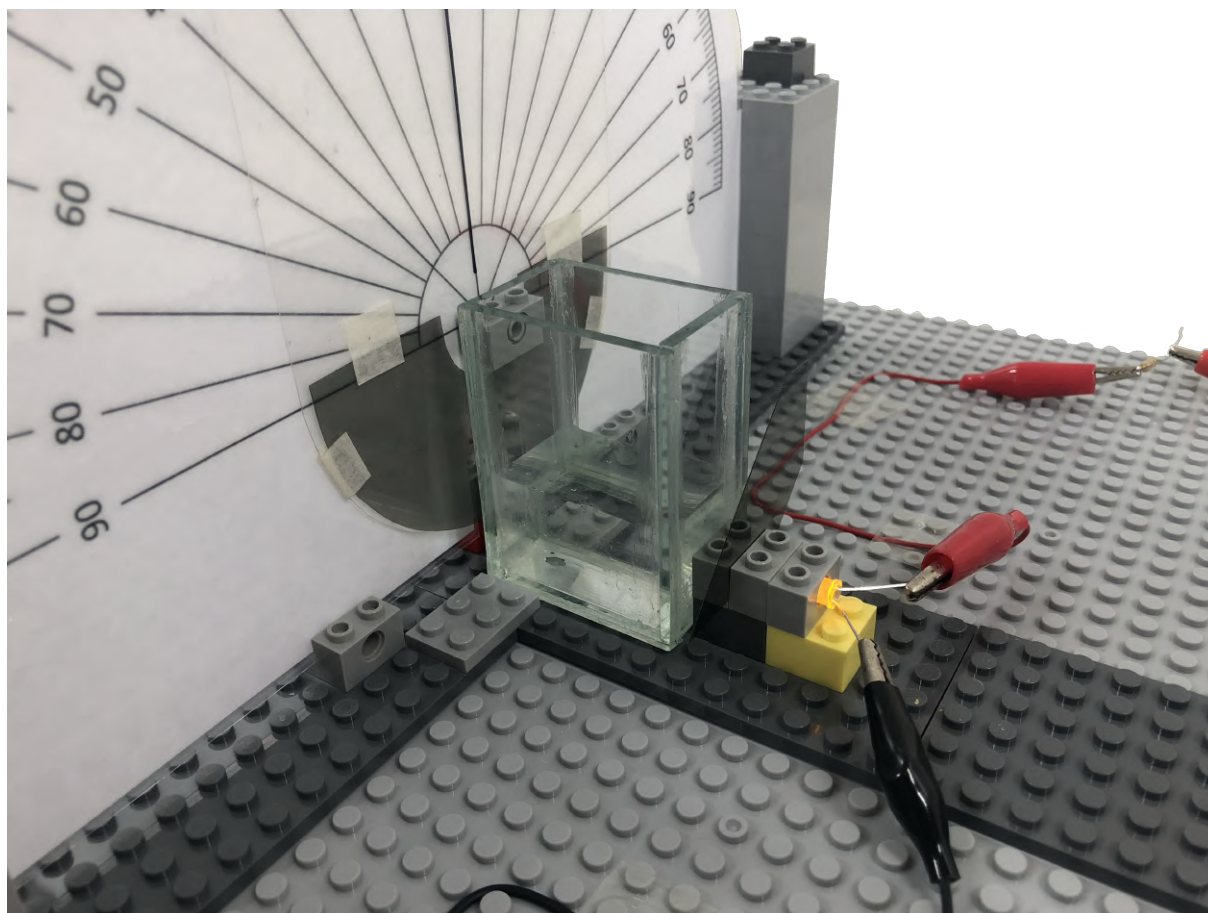


Figure 12. A glass cuvette containing the transparent sample on the polarimeter.

A small amount of the dried sample was introduced into the capillary tube. Once a proper sample was obtained, the capillary tube was allowed to fall through a plastic tubing to compact the sample at the bottom of the capillary tube. The sample height was made not to exceed 2 mm. Figure 13 shows the capillary tube containing the white sample placed in the sample holder, as seen from the glass scope of the apparatus. The apparatus has three sample holders separated by the black column where three samples can be inserted and investigated simultaneously.

In operating the apparatus, specific parameters were established: a target temperature set at least 10°C below the expected or observed melting point of the sample and a gradual ramping rate of $1^{\circ}\text{C}/\text{min}$. For the analysis of ascorbic acid, a target temperature of 180°C (10°C below the theoretical melting point of ascorbic acid, 190°C) was selected. The apparatus was programmed to incrementally increase the temperature until reaching the set target. If the sample began melting before reaching the designated target temperature, the temperature displayed on the screen at the onset of melting was noted. Subsequently, a new target temperature was set, 10°C below the recorded temperature at which the melting started.

The temperatures at which the samples began melting and when complete melting occurred were recorded using the apparatus' temperature monitoring system. This procedure enabled the determination of the melting temperature range for each sample. Additionally, to ensure the accuracy and reliability of the results, each sample underwent three successful trial runs.

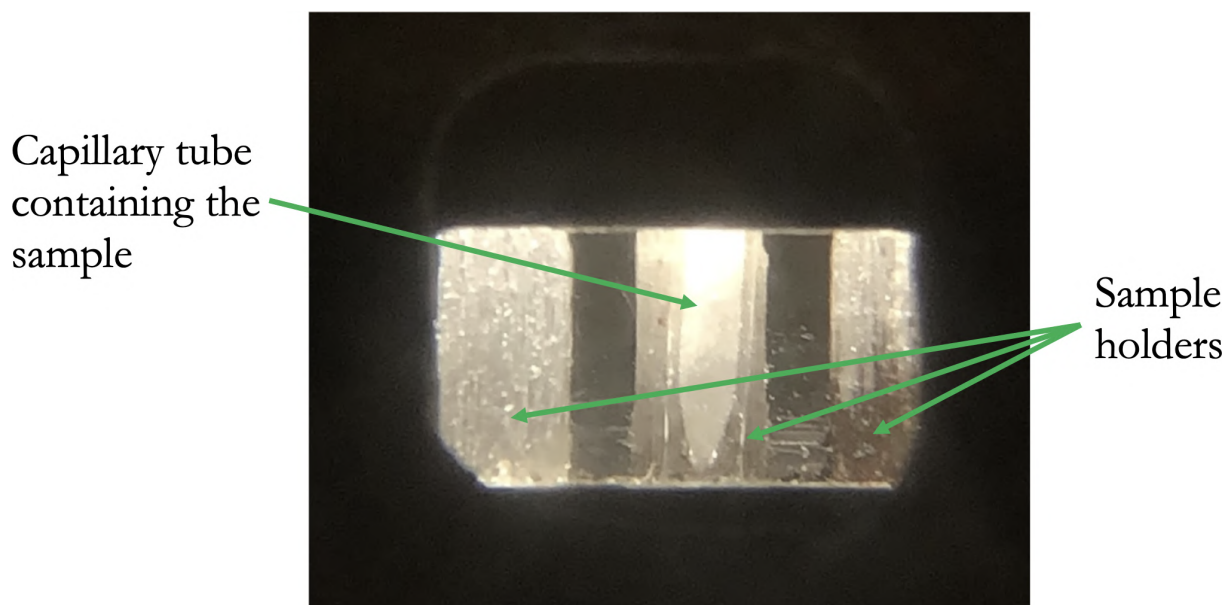


Figure 13. The capillary tube containing the sample observed through the glass scope of the melting point apparatus.

2.4. Post-experiment

The specific rotation was computed first using equation (1) to assess and analyze the observed rotation. Then, the calculated specific rotations were compared to literature values. In the book “The Merck Index - An Encyclopedia of Chemicals, Drugs, and Biologicals”, ascorbic acid has a specific optical rotation of $[\alpha]_D = +20.5^\circ$ to $+21.5^\circ$ in distilled water at 25°C measured using the wavelength of the D1-line emission of sodium lamp which is 589.6 nm [18,19]. If the calculated specific rotations are close to the literature value, then the sample will likely be pure. Otherwise, the ascorbic acid sample is impure.

Moreover, to support and justify the characterization of the sample using a polarimeter, the sample’s melting range determined from the melting point apparatus was compared to the theoretical melting range of the sample. The melting range of ascorbic acid is 190°C to 194°C at which it also decomposes [20]. The melting point is a helpful purity indicator since it tends to decrease and widen its range when impurities are present in larger quantities [21]. The results from melting point determination, which tells whether the sample is pure or not, were used to verify and complement the polarimetry results. Therefore, this study used a comprehensive approach combining polarimetry and melting point determination to enhance the reliability of purity assessments.

3. Results and discussion

3.1. Polarimetry data

Based on the literature, the specific rotation of a compound is derived from the observed rotation when a light source with a wavelength of D1-line emission of sodium lamp (589.6 nm) is used. However, the peak emission wavelength used in the experiment is 592 nm, as indicated in the subscript of the specific rotation. These specific rotations at 592 nm, $[\alpha]_{592}$, were compared to the specific rotation at 589.6 nm, $[\alpha]_{589.6}$. This procedure was similar to that of Kvittingen and Sjursnes [1] in their research. This was also done by Bernard and Mendez [12], wherein they used different light sources (e.g., red, green, and blue LEDs) for their 3D-printed cuvette polarimeter and a sodium lamp for the commercial polarimeter.

While the path length and sample concentration can be easily accounted for, it is noted that the temperature and the wavelength of the light source are nonstandard. Therefore, the values obtained are expected only to be close to the literature [10]. This limitation and procedure are acceptable, especially for classroom demonstrations [10].

Table 1 presents the calculated specific rotation $[\alpha]_{592}$ values derived from the observed rotation α for the two samples of ascorbic acid, conducted at various path lengths and at approximately 25°C temperature. Given that the specific rotation of pure ascorbic acid is reported within the range of $[\alpha]_{589.6} = +20.5^\circ$ to $+21.5^\circ$, the average of this interval, $+21.0^\circ$, was employed for comparison and computation of the percentage error.

Table 1. The observed rotations with the corresponding specific rotations of Brands X and Y for different path lengths and the percent errors when compared to $[\alpha]_{589.6} = +21.0^\circ$.

Sample	Path length l	Observed rotation α	Specific rotation $[\alpha]_{592}$	Percent error
Brand X	0.2 dm	1.0°	20.0°	4.76%
	0.4 dm	2.0°	20.0°	4.76%
	0.6 dm	3.0°	20.0°	4.76%
	0.8 dm	4.0°	20.0°	4.76%
	1.0 dm	5.5°	22.0°	4.76%
Brand Y	0.2 dm	0.5°	10.0°	52.4%
	0.4 dm	1.0°	10.0°	52.4%
	0.6 dm	2.0°	13.3°	36.7%
	0.8 dm	2.5°	12.5°	40.5%
	1.0 dm	4.0°	16.0°	23.8%

For Brand X, the specific rotations closely align with the theoretical specific rotation from the literature, resulting in a relatively low percentage error, averaging 4.76%. Conversely, the specific rotations for Brand Y deviate significantly from the expected theoretical value, yielding percentage errors ranging from 23.8% to 52.4%, with an average error value of 41.2%. These disparities underscore the potential impurities of the latter sample.

Figure 14 depicts the observed rotations as a function of sample path length for Brands X (plotted in blue) and Y (plotted in green), alongside theoretical rotations (plotted in gray) calculated using $+21.0^\circ$ as the specific rotation value. The plot of Brand Y deviates noticeably from the theoretical expectations, which can be attributed to some impurities that affect its optical rotation. Note that the slope represents the specific rotation divided by the 0.25 g/cm^3 concentration. For Brand X, the slope of the best-fit line is 5.23, resulting in a specific rotation of 20.9° , which is within the range of the theoretical specific rotation of ascorbic acid. Meanwhile, Brand Y's slope is given as 3.50, corresponding to a specific rotation of 14.0° , which is outside the expected specific rotations.

The linear plots depict the expected linear relationship between observed rotation and path length, consistent with Biot's law, as expressed in equation (1). The linearity of the relationship for both plots is indicated by R^2 values, which is very close to a value of 1. For Brand X, the R^2 value is 0.9977, while for Brand Y, the R^2 is 0.98.

3.2. Melting point determination

The purity assessment conducted via polarimetry was further validated through melting point determination. Table 2 presents the melting temperature range and average melting point of the two ascorbic acid samples obtained from three trials and the corresponding percentage

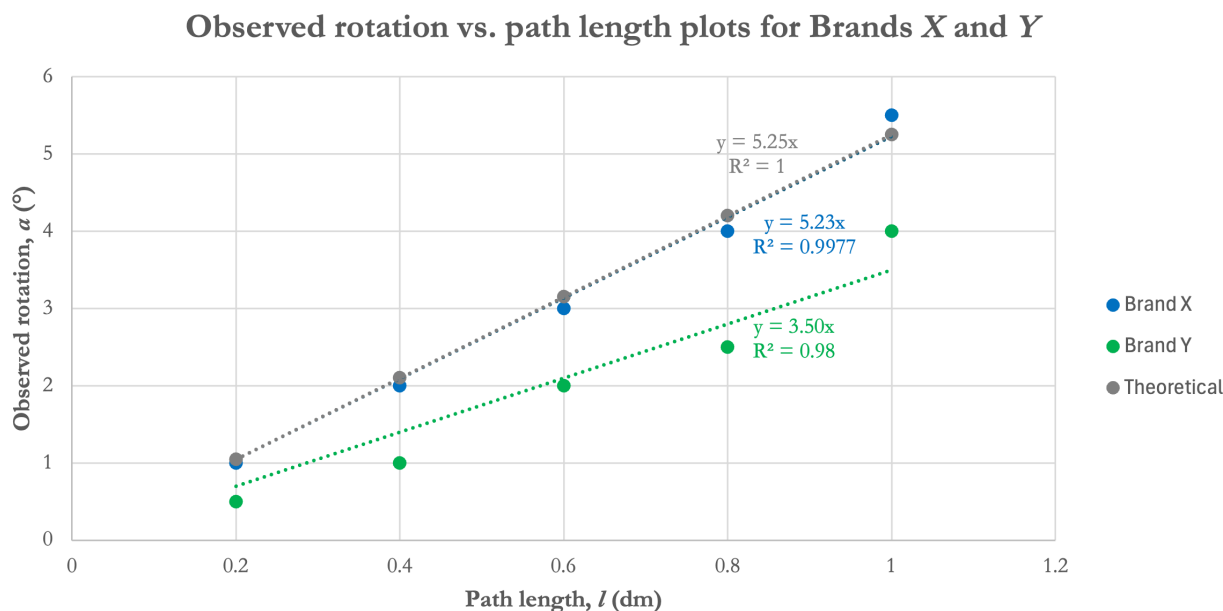


Figure 14. Observed rotations for Brand X (blue) and Brand Y (green) of ascorbic acid compared to the theoretical rotation (gray) as a function of path length.

errors when compared to the average theoretical melting point, 192.0°C. Note that the melting temperature range was computed as the average of the minimum points (i.e., the temperature at which the sample began melting) and maximum points (i.e., the temperature at which the sample completely melted) for the three trials. On the other hand, the average melting point was computed using the minimum and maximum values of the melting temperature range.

Table 2. Melting temperature range and average melting point of Brands X and Y and the corresponding percent errors when compared to the average theoretical melting point, 192.0°C.

Sample	Melting temperature range	Average melting point	Percent error
Brand X	192.7 to 195.0°C	193.9°C	0.990%
Brand Y	128.3 to 146.0°C	137.2°C	28.5%

The basis for analysis is the well-established principle that pure organic compounds exhibit well-defined melting points within a narrow temperature range [17, 22, 23], typically 0.5°C to 2.0°C [17]. In contrast, a broader melting range indicates an impure sample, as impurities tend to lower the melting point and broaden the melting range [17, 23]. A substance is considered to have a sharp melting point if the range is under 5°C, whereas it is deemed to have a broad melting range if the range exceeds approximately 5°C [22]. Thus, the melting point serves as a quick and straightforward method for qualitatively determining the purity of samples, particularly those with relatively low levels of impurities (e.g., approximately less than 10%) [24].

Table 2 reveals that the average melting point of Brand X falls within the theoretical melting range of 190°C to 194°C. Furthermore, the observed melting range is narrow, deviating merely by 1°C from the upper limit of the theoretical melting range. Also, it can be seen that the percentage errors of the average melting point as compared to the theoretical average melting point are minimal, i.e., less than 1%. This convergence strongly suggests a high likelihood of purity for Brand X. Conversely, the average melting point of Brand Y significantly deviates

from the theoretical value, as highlighted by the percentage error, and the observed melting range is broad, strongly implying that Brand Y is likely to contain impurities. Therefore, both polarimetry and melting point determination yielded consistent results for Brands X and Y, indicating that Brand X is likely pure while Brand Y is likely impure.

4. Summary and conclusion

In this study, an improvised polarimeter based on the design by Kvittingen and Sjursnes [1] was adapted and modified to measure the optical rotation of two ascorbic acid samples to assess their purity. While conventional polarimeters often serve as demonstrations of optical activity phenomena, this research took a step further by integrating purity assessment into the analysis.

The polarimetry experiments provided optical rotation values for the two ascorbic acid samples. Brand X of ascorbic acid exhibited specific rotations close to theoretical values, inferring high purity. Conversely, Brand Y of ascorbic acid showed significant deviations from the expected specific rotation, suggesting possible impurities affecting its optical properties.

Additionally, melting point determination experiments further supported the findings from polarimetry. Brand X demonstrated narrow melting ranges consistent with literature values, indicating high purity. In contrast, Brand Y exhibited a broad melting range, significantly diverging from the literature value.

This comprehensive approach combining polarimetry and melting point determination proved to be cost-effective compared to other devices typically used for purity assessment, which are often more expensive. While traditional methods solely focus on optical activity, this study showcased how integrating multiple techniques enhances the reliability of purity assessments. The combination of polarimeter and melting point determination offers a practical and accessible solution for purity evaluation. Furthermore, the findings demonstrated that the polarimeter is not only effective in practical applications, but it also offers educational benefits. Its non-black-box nature facilitates a straightforward demonstration of optical activity and polarization concepts.

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The transformation of children's mental representations of 5-6 year olds for coagulation: precursor models through a storytelling approach

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Abstract. The current study presents the results of a qualitative research on the mental representations of children aged 5-6 years regarding the coagulation of everyday materials. Initially, children's representations on coagulation of butter and chocolate were studied in a pre-test through three different tasks. Subsequently, a teaching intervention was implemented based on a storytelling approach, which is embedded in a socio-constructivist perspective with the aim of establishing a precursor model in children's thinking about coagulation. Finally, in a post-test, children's representations after the teaching intervention were studied. The results of the research showed that children have made significant progress in the post-test as the majority of them recognize cooling as a factor in the coagulation of the above materials.

1. Introduction

The issue of introducing children aged 3-8 years to the phenomena of the natural world has been studied in recent decades by a raising field of research known in the academic literature as Early Childhood Science Education [1–6]. Along this context a long series of research in different cognitive fields such as astronomy [7], plant growth [8], human body [9], state of matter [10], electricity [11], floating and sinking [12], have been carried out with the aim of capturing the initial children's mental representations, their distance from school scientific knowledge, the obstacles encountering by children's thinking regarding the transformation of these representations as well as effective processes for developing teaching activities and learning. The issue of identifying naïve representations is important because it enables us to obtain an initial mapping of early forms of thinking. However, since representations are unstable entities usually at odds with school scientific knowledge due to some systematic barriers of children's thinking, the research was led to overcome these barriers [13–17].

In recent years, especially for the level of early childhood education, narrative and storytelling approaches are often used in the development of teaching activities that create a favorable environment as they stimulate the interest of young children and favor learning [18–22]. Along



this direction, it was found that through specialized teaching interventions, young children are able to construct mental entities about natural phenomena that are compatible with certain characteristics and functions of school scientific knowledge such as the description and prediction of the evolution of phenomena. These entities, which show stability in different settings and utilize the same criteria for formulating arguments and reasoning, have been called precursor models and in recent years have been objects of systematic research [23–26]. In the current study we present an attempt to construct a precursor model for the phenomenon of coagulation with 5–6-year-old children.

The conceptualization of thermal phenomena is a well-developed field of research in Early Childhood Science Education. Indeed, since many physical changes frequently encountered in everyday life are accomplished by simple states of heating or cooling of materials, thermal phenomena are a favorable area for initiating young children into the world of Physics. The main part of the relevant research is related to the study of young children’s mental representations of changes in state of matter. However, relevant research on children of early childhood education ages is scarce and is often confined to the water cycle in nature or to particular changes of state.

In a series of studies on the conceptualization on evaporation and condensation, the findings have highlighted important limitations associated with aspects of “prelogical” thinking that typically dominate children’s intelligent at this age [27]. Thus, young children do not recognize that the amount of water is conserved and therefore the representation that water ceases to exist occurs frequently, while at other times they believe that water that has become water vapor is stored in various places such as furniture or soil [28–31]. Based on these findings, attempts were made to construct teaching activities aimed at transforming these representations. In research with this orientation, teaching environments were designed in which young children were shown to be able to approximate the changes from the liquid to the gas phase and vice versa, as they were assisted by certain centrations in the setups in which the simple experiments were carried out. For example, the bubbles during boiling and their movement from bottom to top or the observation of the transition of water vapor from the containers to the air, allow the transformation of their mental representations [32–34].

Research related to melting and coagulation in early childhood education context is clearly limited. In particular, in research conducted through the process of prediction and confirmation in experiments of state changes with everyday materials such as ice cubes and chocolate [33] it was highlighted the ability of very young children to recognize that changes in the “hardness” of solids and the “fluidity” of liquids are due to heating and cooling. In another study, both children with learning disabilities and typical development children were asked to make estimates of melting and coagulation in a specially created digital environment. The results showed that the majority of children of both groups made correct predictions [35]. Similar data was recorded in another study in which children participated in a special inquiry-based learning sequence. After completing this process, the vast majority of children were able to link the ice with water, to identify that ice is a form of water, to understand why and how ice becomes water and to solve real-life problems or other challenges using the new knowledge [36]. In research on the water cycle, simple experiments were used to study melting and coagulation based on children’s predictions and explanations [37,38]. Findings of these research highlighted a series of difficulties in children’s thinking derived from everyday life. However, through the experimental procedures the possibility of constructing a precursor model was emerged.

The current study presents the research findings on coagulation in the thinking of children aged 5-6 years. The ability of children of this age to deal with this phenomenon has been established both in studies that aimed to capture mental representations [33, 35] as well as in other studies that investigated the issues of constructing a precursor model for water state changes in young children’s thinking [37, 38]. The innovative element of this research is the attempt to utilize a storytelling approach to construct a precursor model. This choice was

made not only because it enriches the teaching perspectives, but also because it is consistent with the context of pedagogical practices that are often adopted in preschool education classroom. Specifically, having explored children's mental representations, a storytelling teaching intervention was implemented in order to overcome the difficulties identified. Thus, the following two research questions were formulated:

1. What are the mental representations of pupils on coagulation?
2. After a storytelling teaching intervention, were the children's mental representations transformed into a precursor model compatible with school knowledge?

2. Methodological framework

2.1. Research design

The current research is qualitative in nature and was conducted in three sub-sequent phases: the pre-test, the teaching intervention and the post-test [39,40]. Data in the pre- and post-tests were collected through individual semi-structured interviews. During the pre-test, children were asked for predictions and explanations in three tasks. The two of them were related to the coagulation of a cube of butter in liquid form which was observed melting on a gas stove while the third task was related to the coagulation of a melted chocolate which was also observed melting on the gas stove. Based on the findings of the pre-test, after two weeks period, a teaching intervention took place in which the issue of water coagulation in the natural environment under conditions of strong cooling was highlighted through the narration of an improvised fairy tale. In the post-test, two weeks after the teaching intervention had taken place, the same tasks that were given in the pre-test were presented to children who were asked for predictions and explanations.

The research was conducted in 6 kindergarten classes in an urban area of the city of Patras (Greece). The implementation of the pre- and post-test took place during the winter period in a special area of the schools outside the classroom. The teaching intervention took place in the same school areas in groups of 4-5 children. All the discussions with the children were recorded and the analysis was done from the transcripts. Non-verbal behaviours were also recorded through the use of a specific written protocol. The children's responses were classified into the same categories for the pre- and post-test and their data were studied comparatively.

For the current research, the consent of the children's parents was requested according to The Ethics Committee of the Department of Educational Sciences and Early Childhood Education of the University of Patras approved the study and consent procedures (the approval No: 4 / 21.2.2022)

2.2. Participants

In the current study participated 99 children (47 boys and 52 girls) with a mean age of five years and five months (S.D. 2 months). A large number of children aged 5-6 years old, that were enrolled in Greek primary schools, were invited to play with the researcher and listen to a story. Those who responded positively to this invitation were finally included in the research sample. These children had not come across to any school activity related to state of matter changes.

2.3. Task in the pre- and post-test

Three tasks were used to explore children's representations of the coagulation of two everyday materials.

Task 1. We put a cube of butter on a metal tray and then we place that tray on the flame of a camping gaz. We also put half of the amount of melted butter on a plate which we place on a table in the room. We ask the children to tell us whether the butter will stay

hard as it was before heated or stay melted as it appears after heating as soon as it we let it outside during the whole cold night.

Task 2. We put the rest of the melted butter in another dish which is placed in the fridge. We ask the children whether the butter will remain as hard as it was before we melted it on the fire, or it will stay melted as soon as we take it tomorrow out of the fridge.

Task 3. We put a piece of chocolate in a transparent container and heat it in the camping gaz until it liquefies. We ask the children to tell us whether we will be able to drink the melted chocolate tomorrow morning as soon as we let it in the classroom during the whole night.

2.4. The teaching intervention

Based on the pre-test findings, a storytelling teaching approach was designed and implemented. Since the important issue that emerged was the difficulty in recognizing the role of the environment as a cooler system compared to a liquid in that environment, a story was created in which the main idea was that the environment can resemble a large refrigerator.

The narrative begins with a very cold winter day in a house near a lake. The parents of a disobedient child have forbidden him to take the boat in the cold afternoon and go for a ride on the lake as the whole family used to do together, because at night the air in the lake is cold as it is in the refrigerator and its water is likely to turn into ice. The child disobeys the parents because he did not believe that the water in the lake will turn to ice. He secretly took the boat and went into the lake. When the sun went down it started to get very cold, and the child felt like he was in the refrigerator. The water froze, the boat got stuck in the ice and could not move forward or backward. After many hours in the lake, the parents searched for the child and with large fires melted the ice and the boat became unstuck. When the parents scolded him for disobeying, he apologized telling them that he could not believe that the air in the lake around the boat would be as cold as the refrigerator to cause the water to freeze.

The narrative was dialogic and interactive in nature. The researchers answered every question and built on every observation made by the children, with the emphasis given on the relation between cold air and refrigerator. During the discussion the children were shown pictures of trapped boats in frozen lakes (figure 1).



Figure 1. Boats on frozen lakes.

2.5. Data analysis

The children's responses, which correspond to different mental representations, were classified into three distinct categories based on their distance from the school scientific knowledge. In particular, they were classified into the following three categories: (a) sufficient, (b) intermediate

and (c) insufficient. In ‘sufficient’ category were classified those responses that were compatible with school scientific knowledge, i.e. attribute coagulation to cooling. Answers in which the children’s reasoning had shortcomings or contradictions were characterized as ‘intermediate’. Finally, answers that had nothing to do with school scientific knowledge were described as ‘insufficient’.

The analysis and classification of responses before and after the teaching intervention were evaluated by two different researchers, among whom there was more than 90

3. Results

The frequencies of children’s responses to the three tasks in the pre- and post-test as well as the categories of responses along with typical examples that were given by the children are presented below. Children were numbered from 1 to 99. It should be noted that as there were found no differences with regard to children’s gender, the presentation refers to the whole sample.

Table 1 presents the results in all three tasks for the pre- and post-test.

Table 1. Frequencies of pupils’ responses.

	Task 1		Task 2		Task 3	
	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Sufficient responses	–	51	17	76	4	69
Intermediate responses	31	19	73	21	56	20
Insufficient responses	68	29	9	2	39	10

3.1. Responses to Task 1: the melted butter in the environment

Children’s responses to Task 1 were classified into three categories.

Sufficient responses. Here were classified those responses in which it was recognized that the butter will congeal during the cold night. Quite interestingly, sufficient responses were obtained only during the post-test. For example, Student 33 (S33), post: ‘*The butter will become hard again as it was before we melted it in the fire... [Researcher (R): Why? How do you think that?] ... It will cool down during the cold night.*’

Intermediate responses. Here were classified those responses that while acknowledged that the melted butter will get cool, they did not link cooling to possible coagulation. For example, S71, pre: ‘*If left overnight in the classroom the butter will get very cold... It’s cold in here in the morning when we come in....*’

Insufficient responses. Here were classified those responses that did not referred to the thermal condition of the environment at all. For example, S4, pre: ‘*There will be butter on the table. In the morning we will take it from there... that’s where Maria sits....*’

3.2. Responses to Task2: the melted butter in the fridge

Children’s responses to this Task were also classified into three categories.

Sufficient responses. Here were classified those responses that acknowledged that the butter would congeal when placed in the fridge. For example, S54, post: ‘*The butter will freeze in the fridge... it will turn to stone....*’

Intermediate responses. Here were classified those responses that while acknowledged that the melted butter will cool, they did not make any reference to coagulation. For example, S11, pre: ‘*In the refrigerator the butter will cool down a lot... but I am not sure if it will get hard like before....*’

Insufficient responses. Here were classified those responses that did not refer to the cooling of butter at all. For example, S47, pre: ‘*In the fridge it will stay the same... (R: Why?) ... I don't know...*’.

3.3. Responses to Task 3: the melted chocolate in the environment

Children’s responses to this Task were also classified into three categories.

Sufficient responses. Here were classified those responses that acknowledged that the chocolate will congeal as soon as it would be left in the cold environment. For example, S54, post: ‘*We won't be able to drink the chocolate... it will become normal chocolate again in the cold. Then we can eat it*’.

Intermediate responses. Here were classified those responses that while acknowledged that chocolate will cool, they did not make any reference to coagulation. For example, S70, post: ‘*The chocolate will freeze during the night... your throat will get cold when you drink it in the morning.*’

Insufficient responses. Here were classified those responses that did not refer to chocolate cooling. For example, S82, pre: ‘*The chocolate will be a hot drink... (R: The next morning will be a hot drink too?) ... Less, since it's been so long*’.

4. Discussion

In the current qualitative research, mental representations of 5-6 years old children about coagulation as well as the possibilities of their transformation after a storytelling teaching approach were studied.

With the first research question we tried to record the various mental representations of young children in three different settings. The research data highlighted the difficulty of children to conceptualize coagulation phenomena, a fact that is in line with the limited international literature in this area [33, 35]. This particular difficulty was not only confined into situations where coagulation occurred in the physical environment, as in Task 1 and 3, where it was almost impossible for children to conceptualize it as a source of receiving the heat to which the coagulation of butter and chocolate took place. In contrast, it was also found in Task 2 where the source of cooling was a well-known machine from everyday life such as a refrigerator. Indeed, as it was found only 17% of the children recognized that in the fridge the liquid butter will transformed into the solid state.

In the second research question, an attempt was made to capture the effect of the storytelling teaching intervention on children’s mental representations. Evidently, engaging children in storytelling had a significant effect on their thinking since more than half of them associated in each task cooling with coagulation. In particular, in Tasks 1 and 3, almost 51% (vs. 0% in the pre-test) and 70% (vs. 4% in the pre-test) of children recognized that both melted butter and chocolate will return to their original solid state as soon as they left in a cold environment for a few hours. In Task 2, almost 77% of children (vs. 17% in the pre-test) identified the refrigerator as an environment that causes melted butter to coagulate. This finding is of particular interest as it seems that the function of an appliance that falls within the children’s everyday experience begins to act not only as a familiar cooling-preserving/storage space for food, but also as a system involved in thermal exchanges.

The recognition of the refrigerator as a tool that causes coagulation is probably linked to the understanding of the wider environment as a space that has analogies with the refrigerator, since this analogy was reinforced in the narrative by the reference to the air around the boat that was persistently characterized as a refrigerator. However, the consistency of this type of reasoning that was found across all Tasks in the post-test acts as a precursor model in children’s thinking as it enables them to predict and describe coagulation processes of liquid materials found in environments to which strong cooling potential is attributed. In this respect, it was

apparent that early childhood children are capable of constituting precursor models regarding liquid coagulation. Indeed, in the relevant literature [37,38], it has been pointed out that through appropriate teaching interventions, young children are able to overcome the obstacles that naïve mental representations create for them and to be led to entities that produce stable reasoning, compatible with school scientific knowledge.

It should be noted here that the precursor model does not include the mechanism of interaction between hot and cold systems, i.e. the issue of thermal equilibrium. The concept of thermal equilibrium requires high abstraction and is combined with heat as a concept and therefore far exceeds the thinking capabilities of children of this age.

The storytelling approach used in this research is an alternative approach to guide young children's thinking to critical transformations. It is one of the several approaches that are based on different socio-cultural aspects of children's everyday life and education, such as the use of play and imagination [41–44], modern digital technologies [45,46]. In recent years, significant research efforts have been directed along this line, which gradually constitute a broader area of theory, research and pedagogical applications well known as Early Childhood Science Education.

5. Study limitations

The small sample which was consisting of children recruited from a small number of schools, undoubtedly serves as a major limitation of the study. This is also the case for the qualitative approach which was confined into the usage of familiar materials. Undoubtedly, data of quantitative approaches combined with the comparison of children's reasoning between familiar and non-familiar materials will allow to study the stability of precursor models.

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Tracking the terminal velocity and energy of a parachutist: A video analysis for Physics classroom experiment

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Tracking the terminal velocity and energy of a parachutist: A video analysis for Physics classroom experiment

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Abstract. This study primarily focuses on tracking a parachutist's terminal velocity and energy during a free fall using video analysis. Also, this study looks into related literature about the implications of this experiment for classroom practice. High-quality and slow-motion videos of free-falling slotted masses acting as parachutists were captured, and the terminal velocities and energies were analyzed through software tracker video analysis and modeling. The data from the software revealed that, indeed, the terminal velocity is directly proportional to the square root of the masses. The 200g parachutist reaches terminal velocity first, then the less massive parachutist. The generated kinetic energy, gravitational potential energy, and total mechanical energy graphs were similar to the literature. The tracker video analysis can indeed track a parachutist's terminal velocity and energy. However, the acceleration due to gravitational needed to be measured correctly due to some errors in the experiment. Furthermore, the literature has cited positive and negative implications for classroom practice. This study can say that the positive outweighs the negative. The positive repercussions were about enhanced engagement, accuracy, and data precision, while the negative ones were about the school's technological divide.

1. Introduction

Terminal velocity is the constant speed at which an object falls or moves through a fluid due to drag force. It is also the highest speed at which an object falls through a fluid (such as air) due to gravity. This speed is achieved when the force of air resistance acting on the object is equal and opposite to the force of gravity pulling it down [1]. At terminal velocity, the net acceleration of the object becomes zero, and it moves with a constant velocity.

The terminal velocity of a parachutist in the air depends on several factors, such as their body position, the surface area of their parachute, and the density of the air they are falling through [2]. Furthermore, Pople and Harris [3] detailed that as the parachutists jump out of the plane, they will accelerate as gravity pulls them downwards. As they gain speed, the air resistance acting on their body also increases. At a certain point, the air resistance will become strong enough to balance out the force of gravity, and the parachutist will stop accelerating and reach terminal velocity.

In a classroom experiment on terminal velocity in air, a ball of known weight and size is dropped from a height while being constantly video recorded, like the study of Jetly et al. [4] and Cross [5]. The video is then played in slow motion to observe the ball's movement as it



falls toward the ground due to gravity against the opposing force of air resistance. Terminal velocity is reached when the gravitational force pulling the ball downward is balanced by the air resistance pushing up against the ball. The terminal velocity can be calculated by analyzing the speed at which the ball falls through the air and how quickly it reaches its maximum speed or terminal velocity.

However, some classrooms experimenting with terminal velocity in the air can be prone to different sources of uncertainties and limitations. Measurement errors can occur due to the limitations of the measuring instruments, such as a stopwatch or ruler [6]. The presence of air turbulence can cause fluctuations in the velocity of the object being dropped, affecting the accuracy of the results [7]. Systematic errors can occur when there is a consistent deviation from the actual value due to factors such as experimental design or procedural errors.

A video analysis tool called Tracker can help reduce measurement uncertainties. Tracker video analysis is software that allows users to track and analyze the motion of objects within a video [8]. It is commonly used in physics education, as it will enable students to apply their knowledge of motion to real-life scenarios. The software uses algorithms to track the position and movement of an object over time. Users can then analyze the data to calculate speed, acceleration, and velocity. This data can create graphs and charts that help visualize the object's motion [9].

The traditional method of measuring the acceleration due to gravity has limitations, including human error in timing the pendulum's period and limitations on the precision of the measurement. Video analysis offers an improvement over the traditional method by removing human error and providing additional data. However, video analysis requires more advanced technology and software than the traditional method, making it less accessible to some teachers and students.

This paper used this tracker software to analyze the free fall of a parachutist. The objectives are to 1) determine the terminal velocity of different masses of parachutists; 2) determine the relationship between the terminal velocity and masses of the parachutists; 3) verify the generated kinetic energy versus time graph and gravitational potential energy vs. time graph from the literature; 4) determine the classroom implications of using Tracker Video Analysis on free fall experiments as cited in the literature. This research intends to reduce the sources of uncertainty by using this tracker video analysis software.

1.1. Theoretical background

Terminal velocity in air can be defined as the constant speed at which a freely falling object no longer accelerates due to the air's resistance. When an object falls, initially, it experiences acceleration due to gravity. As it falls faster, it pushes the air particles out of its way, generating upward air resistance force, otherwise known as drag.

$$\text{Resultant force}(F) = \text{Weight}(W) - \text{Dragforce}(D) \quad (1)$$

The drag force arises due to the interaction between the object and the surrounding air particles, which slows down the object's forward motion. The amount of drag force depends on many factors, such as the object's size, shape, velocity, and the properties of the air, such as its density, viscosity, and pressure. The equation gives a typical formula used to calculate drag force.

$$D = 1/2C_d\rho v^2 A, \quad (2)$$

where D is the drag force, C_d is the drag coefficient, ρ is the air density, v is the object's velocity, and A is the cross-sectional area of the object perpendicular to the direction of motion.

At some point, the air resistance becomes equal to the gravitational force, and the object no longer accelerates but falls at a constant speed, the terminal velocity.

$$W = 1/2C_d\rho v^2 A \quad (3)$$

Therefore, the magnitude of v

$$v = \sqrt{\frac{2mg}{C_d\rho A}} \quad (4)$$

If the terminal velocity versus the square root of mass is plotted, the gradient equals equation (5).

$$\text{Gradient} = \sqrt{\frac{2g}{C_d\rho A}} \quad (5)$$

The gravitational potential energy (GPE) and kinetic energy (KE) of a free-falling parachutist is

$$GPE = mgh \quad (6)$$

$$KE = \frac{mv^2}{2} \quad (7)$$

In equations (6) and (7), m is the mass of the falling parachute, g is the acceleration due to gravity, h is the object's vertical position above the ground, and v is the object's velocity.

The equation (4) is the terminal velocity equation. The terminal velocity equation describes the maximum speed at which an object falls through a fluid (i.e., air or water) due to opposing air resistance. Essentially, the equation states that two opposing forces are acting on a falling object: pulling gravity down and air resistance pushing it up. As the object falls faster, the air resistance increases until it reaches a point equal to the force of gravity pulling it down. At this point, the object stops accelerating and reaches its terminal velocity.

Objects with more weight will reach a more incredible terminal velocity than lighter objects [10]. This is because a higher air resistance force is needed to balance the importance of the heavier object, and this force requires increased speed. Thus, heavy objects will descend more quickly through the air than lighter ones.

2. Method

2.1. Materials and experimental setup

The parachute was made from 25 cm \times 25 cm plastic, and the string was made from a cloth thread of four pieces, each length of 15 cm. The mass of the parachute is 12.51 g. The basket attached to the parachute, where loads were kept during the free fall, has a dimension of 10 cm \times 10 cm. The center of mass of the basket was drawn by a 2cm diameter circle using a pen. This marked the center of mass the auto tracker looked into during the fall.

Six masses are used: 20 g, 40 g, 60 g, 80 g, 100 g, and 120 g. The clamped mobile phone is fixed into the retort stand, and the height should parallel the meter ruler. The height of the clamped mobile phone to the base is approximately the exact height of the meter ruler. Only one parachute was used to maintain a constant air resistance while the masses were added every drop until 40 g.

Once the materials were set up, the 20 g mass was loaded into the parachute. The mobile phone camera was turned on and tuned to capture slow motion. This drop's free fall was arrested. Then, another 20 g was loaded until the final loading of 120 g, and the mobile phone captured its slow-motion descent.

The system requirements for Tracker video analysis and modeling software work with Microsoft Windows, Mac OS X, or Linux operating systems. The processor should be at least Intel Core i5 or higher. The RAM should be 8 GB or higher, and the Runtime Environment (JRE) of Java 8 or later is recommended [9].

The videos were uploaded in the Tracker Video Analysis. The footage was filtered by rotating it to an upright position. Since the footage contains pre-freefall details, these were ignored and immediately forwarded to the free-fall time.



Figure 1. This paper's materials include a retort stand, meter ruler, masses, and a do-it-yourself parachute made from cloth and cloth tread.

The calibration stick was clicked to match the length of the meter ruler. This gave the Tracker the idea that such a frame equals one meter in length. In addition, the coordinated axis was clicked to inform the Tracker of the x and y-axis components of the fall.

In this experiment, the researcher used manual auto-tracking by using shift + control and clicking the marked center of mass. There were instances when the auto tracker could not track the significant center of mass, so it was connected again.

2.2. Experimental procedure

The independent variable of this study was the mass, while the dependent variable was the terminal velocity. The drag coefficient, the air density, the cross-sectional area of the parachutists or the masses, and the cross-sectional area of the parachute remain constant. The air density was relatively stable since the room where this experiment was conducted was the same. To reduce air mass disruption, the room’s windows were closed, along with the room ventilation. Since the cross-sectional area of the parachute and the mass are the same, the drag coefficient is also estimated to be constant.

The masses were measured using a mass balance, although the slotted masses have labels already. The terminal velocity was calculated using equation (4) theoretically, but practically, the tracker video analysis measured the terminal velocity from the constant gradient of its graph.

On the right portion of the tracker platform, the graphs in two coordinates can be seen (figure 2). The distance on the y-axis versus time was chosen because the object is falling in the vertical direction. The chart can be enlarged by right-clicking on the graph and choosing to analyze it, generating a line of best fit. The portion of the graph where the line seemed straight-line was considered the terminal velocity.

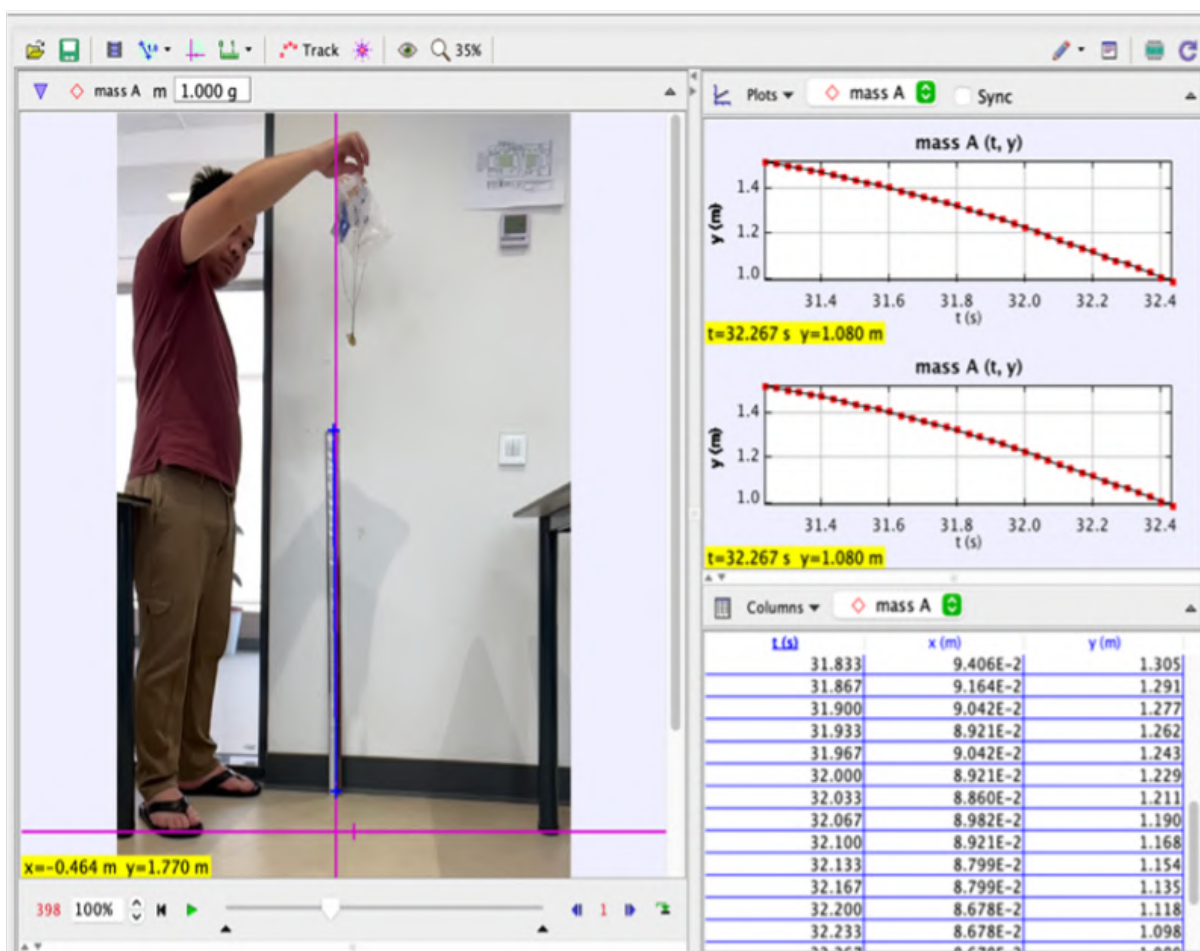


Figure 2. An additional requirement is a mobile phone and computer with tracker video analysis — photo from tracker video analysis [9].

3. Results and discussion

3.1. Terminal velocity (displacement vs. time graph)

Six masses were loaded into the parachute and acted as the parachutist. First was 20 g, then 40 g, until the load was 120 g. The cross-sectional area of the parachute remained the same throughout the experiment.

The graph in figure 3 shows that terminal velocity was achieved between 41.1 seconds and 41.7 seconds. The Tracker software automatically calculated this terminal velocity (-1.24 ± 0.01) m/s. The R^2 value is 0.998, meaning that the data on the line of best fit is 99% reliable.

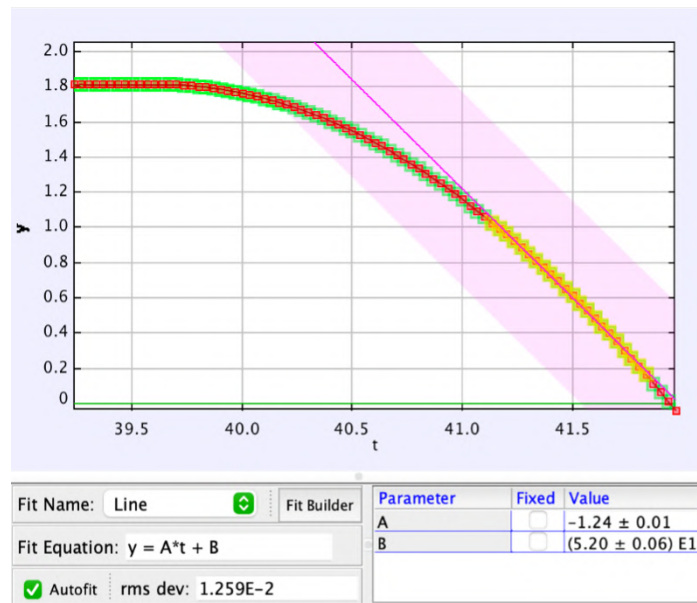


Figure 3. The terminal velocity of a 40 g parachutist is (-1.24 ± 0.01) m/s.

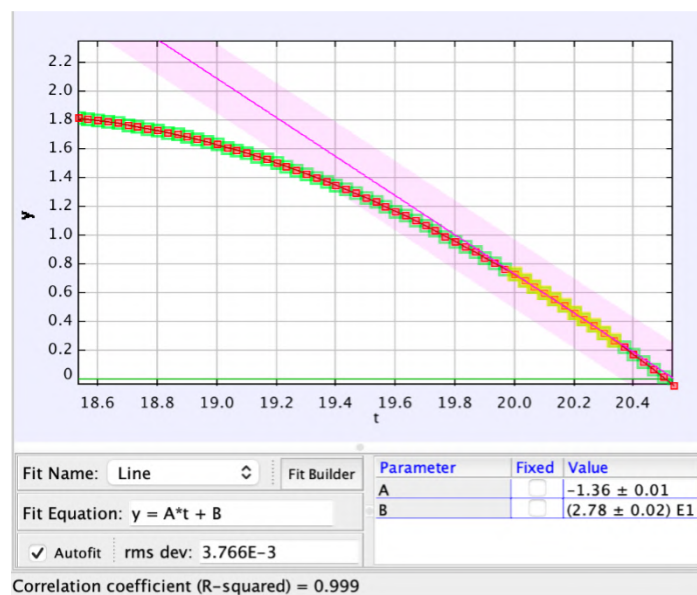


Figure 4. The terminal velocity of a 100 g parachutist is (-1.36 ± 0.01) m/s.

The graph in figure 4 reveals that the terminal of a 100 g parachutist is (-1.36 ± 0.01) m/s, which is higher than the terminal velocity of the 40g load. This is because more massive objects have a greater gravitational force acting upon them, allowing them to accelerate faster than less massive objects. This idea is the implication of equation (4).

When a massive object falls in a gravitational field, it experiences a force due to gravity. As it falls, the force due to gravity initially increases because the distance between the object and the center of the Earth decreases [3]. However, as the thing gets closer to the ground, the force of air resistance acting on it increases until it becomes equal in magnitude and opposite in direction to the gravitational force. At this point, the net force acting on the object becomes zero, resulting in a constant velocity called the terminal velocity. The terminal velocity for a massive object would be reached earlier than a less large object as it can overcome the resistance caused by the air more quickly due to its more significant weight and, therefore, has a higher terminal velocity [2]. This observation is why heavier objects reach terminal velocity sooner than lighter ones.

3.2. Terminal velocity vs. masses of the parachutists

The terminal velocity was gathered from the gradient of the y -displacement against the time graph generated by the Tracker. These terminal velocities increased as the square root of the total mass increased, as seen in table 1.

Table 1. The summary of mass, square root of mass, and terminal velocity of the parachutist.

mass (kg)	\sqrt{mass} (kg ^{1/2})	terminal velocity (m/s)
0.032	0.180	1.18
0.052	0.229	1.24
0.072	0.269	1.28
0.092	0.304	1.32
0.112	0.335	1.36
0.132	0.364	1.41

The masses seen in table 1 were the combination of mass from the load, the basket, and the parachute. The square root of these masses was taken because a graph of the terminal velocity versus the square root of mass was plotted in figure 5. Equation (4) tells us that the y -axis is terminal velocity, and the x -axis is the square root of mass.

The plotting of points and graphing was done in Microsoft Excel using the scatter plot diagram. The formed graph is a straight line of best fit. This concept only validates the relationship between the terminal velocity and the square root of mass. The gradient of this graph is 1.21, which is equal to equation (5). The R^2 value is 0.9934, representing the data's good fit and precision. Figure 6 implies that this experiment on terminal velocity and masses is correct since it followed the relationship in equation (4).

However, equation (4) tells us that the data should have no y -intercept, and figure 4's y -intercept is 0.9589. It is correct to say that an object's terminal velocity increases as its mass increases. However, this relationship is not linear since the drag force on the object also depends on factors such as its surface area, shape, and the properties of the medium it is moving through [11].

Heavier objects generally have a higher terminal velocity than lighter objects. The exact relationship between mass and terminal velocity may depend on the specifics of the object and its environment. In this experiment, the coefficient of drag force and air density were only

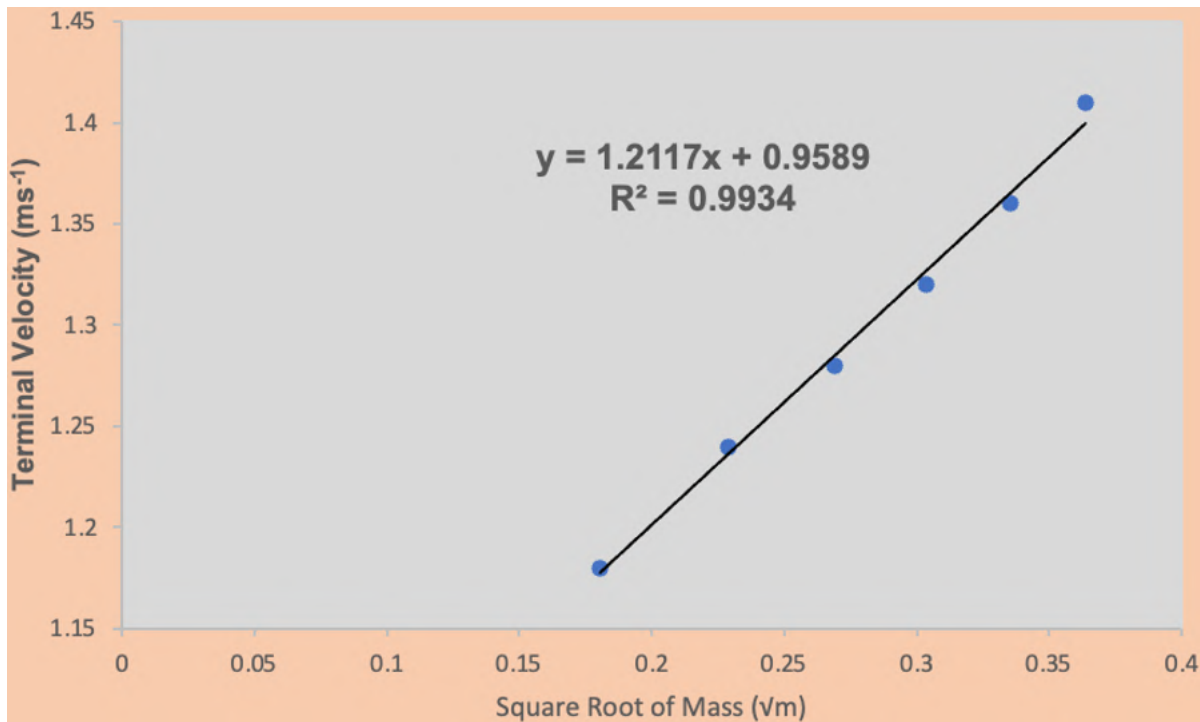


Figure 5. The terminal velocity versus the square root of mass generated a straight-line best fit.

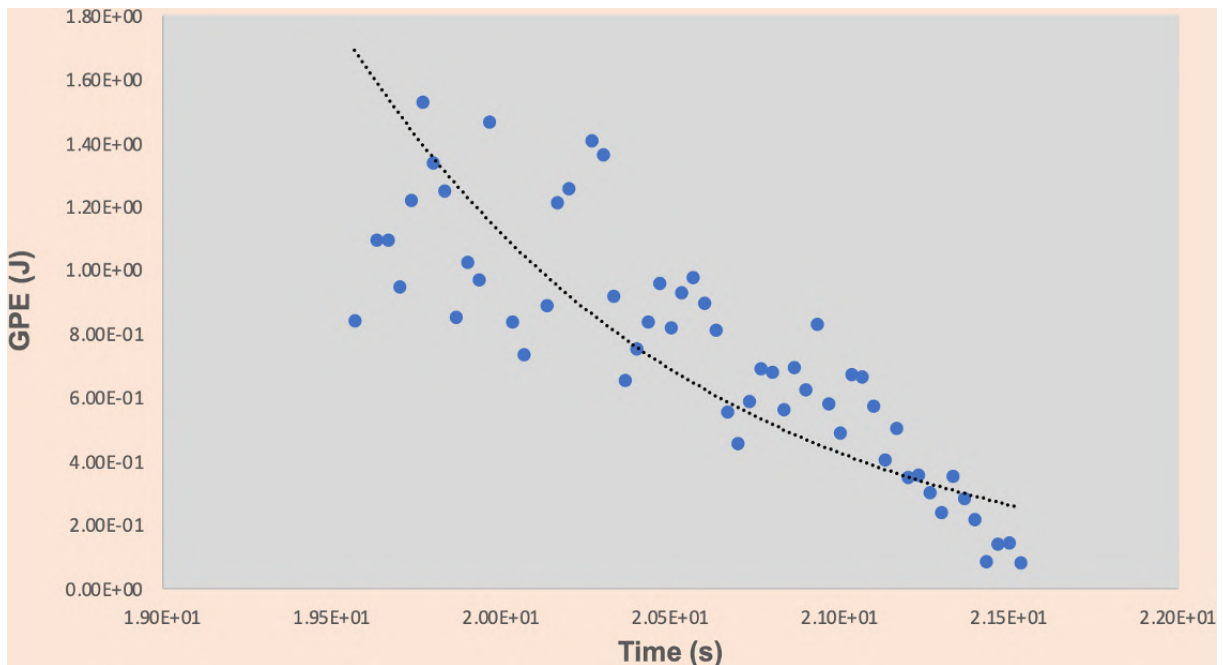


Figure 6. The gravitational potential energy of a 100 g parachutist.

assumed constant, but theoretically, this can vary from time to time. This is the limitation of this research.

3.3. Energy of the free-falling parachutist

The data from the gravitational potential energy (GPE), kinetic energy (KE), and total mechanical energy (TME) that was generated from the Tracker were transformed into Microsoft Excel data. The graphs of the energies were produced from Microsoft Excel.

As a parachutist, free fall they have both kinetic energy and gravitational potential energy. When a parachutist free falls, their GPE is converted into KE as it approaches the Earth. As the parachutists fall, their KE increases due to their increasing velocity, and their PE decreases due to their decreasing height [12].

Kinetic energy is the energy of motion. In this case, the parachutists have kinetic energy because they move as they fall through the air. An object's kinetic energy can be calculated using the equation $KE = mv^2/2$, where m is the object's mass in kilograms, and v is its velocity in meters per second. Brown [13] explained that the faster the parachutist falls, the more kinetic energy they have.

On the other hand, gravitational potential energy is the energy an object possesses due to its position in a gravitational field. Sanjay et al. [14] presented that the higher the thing is off the ground, the more gravitational potential energy it has. In the case of a parachutist free falling, their gravitational potential energy is highest when they first jump out of the plane or off their starting point (such as a bridge or a building). As they fall, their height decreases, and their gravitational potential energy decreases accordingly.

The gravitational potential energy of a free-falling object is decreasing, as shown on the graph in figure 6. The decrease in the GPE is attributed to the reduction in height since the GPE is proportional to the vertical position of the parachutist. However, as revealed in figure 7, the kinetic energy is increasing. The increase in KE is due to the increasing speed of the parachutists. This only means that the loss in GPE is converted into KE of the free-falling parachutist [15]. The total mechanical energy of a free-falling body remains constant throughout its fall, as no external force acting on the body could add or remove energy. Therefore, the graph of total mechanical energy versus the time of a free-falling body would be a horizontal line (a flat line) at a constant value—the diagram is approximately near constant, which is correct based on the literature. The error lies in the fact that the work done on air resistance should have been considered in this research. These three figures are generated in the Tracker Video Analysis and Modeling itself. Both graphs are correct since different studies and books revealed similar charts like those of [16].

When the parachute is deployed, the wind resistance slows down the speed at which the parachute falls to the ground. Therefore, the KE decreases, and the PE increases as the parachutist ascends back towards their starting height, initially at a faster rate but then slowing down until it reaches zero again.

When the parachutists begin free-fall, their GPE decreases as they descend, and their KE increases due to their velocity. As the parachute opens, the KE decreases, and the PE increases as the parachutist ascends to their starting height.

3.4. Classroom implications of this experiment

Using tracker video analysis for classroom experiments on free fall can have several positive and negative implications. While implementing video tracker analysis for classroom experiments on free fall can be challenging, its potential benefits outweigh its limitations if approached effectively with suitable preparation and training.

The positive implications are enhanced learning experience, improved accuracy and precision, time-saving, and increased engagement. Students can see the motion of the object in free fall from different perspectives and can manipulate various parameters such as time, distance, speed, and acceleration [17]. Tracker software allows students to accurately and precisely measure the position and velocity of an object in real time using multiple video frames. Instead of manually

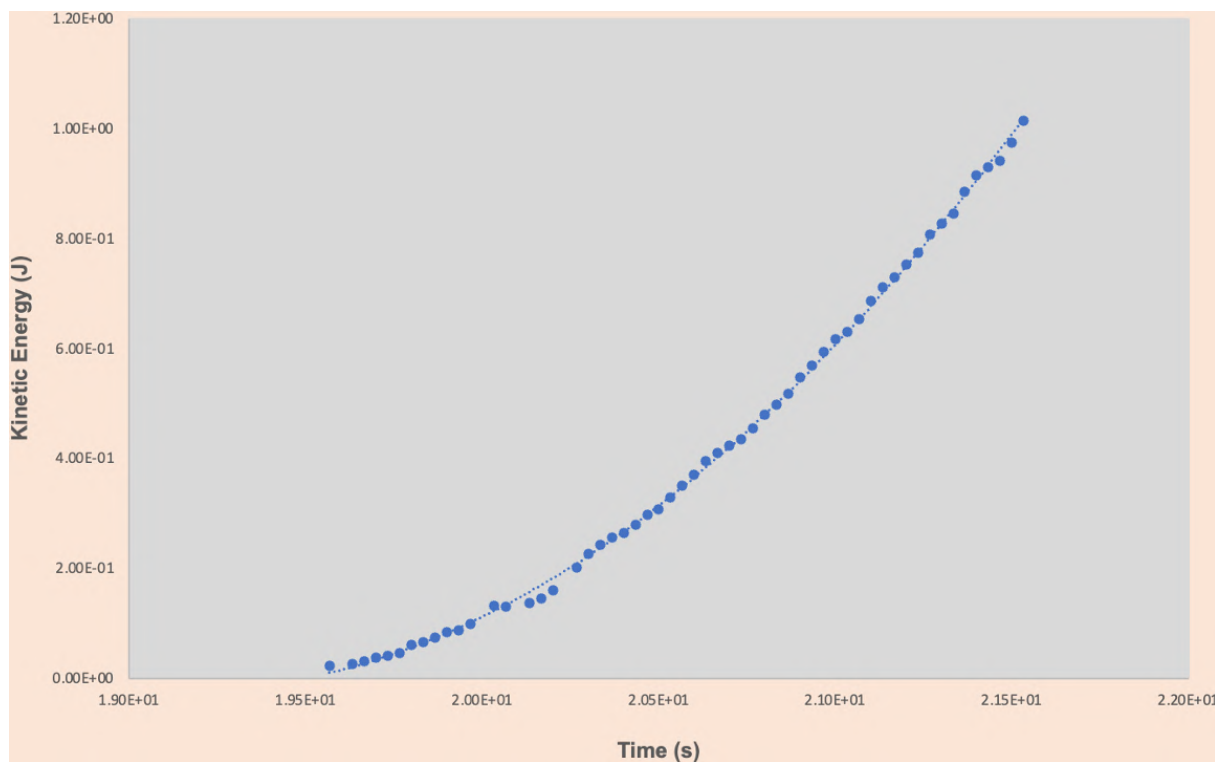


Figure 7. The kinetic energy of a 100 g parachutist.

collecting data, students can use tracker software to capture, analyze, and display motion data in minutes [18]. The use of technology in the classroom enhances student engagement [19].

The negative implications are resource needs, technical difficulties, and implementation challenges. Video analysis requires specific equipment such as cameras, computers, and trackers. This can pose a challenge for schools with limited resources. Ash et al. [20] argued that working with newly acquired tracking technology may lead to unexpected technical difficulties with hardware, software, or even skills required to use it properly. In addition, Gedro et al. [21] observed that there might be a learning curve for both students and teachers when implementing the new method, which poses extra preparation time demands and teacher training.

4. Conclusion

Tracking a parachutist's terminal velocity and energy through video analysis is complex yet fascinating. The process entails careful control of variables that might affect the independent and dependent variables. The tracker video analysis tool is so sensitive that even just a wrong input of the calibration stick can create errors in the experiment.

This experiment proved that tracker video analysis can determine a parachutist's terminal velocity and energy. The data on terminal velocity versus the square of the parachutists' masses were consistent with the theoretical perspective. The straight line of best fit in Figure 6 proves this hypothesis. The gravitational potential energy, kinetic energy, and total mechanical energy graphs were also consistent with the literature. However, the total mechanical energy graph was not entirely constant because the work done by the air resistance was not considered.

Moreover, the literature provided mixed input about the use of tracker video analysis. Tracker video analysis allows for more accurate measurements of terminal velocity than traditional methods, such as timing a falling object. This can be a positive learning experience for students

as they are exposed to new technologies and gain a better understanding of physics concepts such as acceleration due to gravity and air resistance. However, using tracker video analysis requires access to appropriate software and hardware, which may not be available to all classrooms. Furthermore, setting up the equipment and analyzing the data can take time and effort, which may limit the time available for other learning activities. The Tracker requires time and practice to consume the needed technical skills completely.

For future experiments, teachers and students can try moving the clamped camera three to four meters away and increasing the drop height. This can increase the probability of measuring the terminal velocity precisely. Teachers and students should also ensure the clamped camera is parallel to the meter ruler. The calibration stick in the tracker tool should be placed correctly, and the meter ruler should be 1.00 meters.

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Rapid foresight: Information technologies in Physics lessons

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Rapid foresight: Information technologies in Physics lessons

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Abstract. This research, conducted as part of the curriculum in the discipline of Modern Learning Technologies, explores strategies for improving the training of future teachers in response to the dynamic educational landscape. The discipline is an integral component of the educational program designed for students aspiring to become educators. A total of 12 students participated in the study, engaging in a collaborative and iterative process to identify key areas for enhancement in teacher training. The rapid evolution of learning technologies necessitates a proactive approach in preparing future teachers for the challenges and opportunities in the educational landscape. In this study, students enrolled in the educational program for prospective teachers played an active role in the research process. The objective was to leverage the insights and perspectives of these students to identify areas for improvement in teacher training. Twelve students participating in the study were enrolled in the Modern Learning Technologies course. This cohort engaged in a rapid foresight approach, involving activities such as focus group discussions, brainstorming sessions, and collaborative workshops. The methodology aimed to gather diverse opinions on emerging trends in education and technology and to envision potential future scenarios. The findings of the study highlighted key trends in modern learning technologies, including advancements in educational technology, shifts in learning preferences, and evolving classroom dynamics. Students actively contributed to scenario-building exercises, providing valuable input into the skills and competencies they deemed essential for future teachers. The assessment of current teacher training programs revealed areas where adjustments and enhancements were deemed necessary. The active involvement of students in the research process proved to be instrumental in gaining firsthand insights into the needs and expectations of future educators. Collaborative workshops facilitated a co-creation of strategies for improving teacher training programs, ensuring that the enhancements were aligned with the dynamic nature of the educational environment. This research, conducted within the framework of the Modern Learning Technologies course, emphasizes the significance of involving students in the foresight process for enhancing teacher training. The collaborative and iterative nature of the approach ensures that the strategies developed are responsive to the evolving trends and needs in education. As the educational landscape continues to evolve, incorporating student perspectives into teacher training becomes imperative for fostering effective and adaptive educators.

1. Introduction

Education is the foundation of human progress. Socio-economic development in the twenty-first century depends on the ability of the State to provide education to all members of society in order to enable everyone to succeed in the face of rapid change.



The effectiveness of the education system directly depends on the quality of pedagogical activity. What should a teacher of the new era be like? What is the innovative culture of a teacher? Answers to these and other questions will largely determine the further modernization of the education system. Adaptability to the changes of the dynamically changing world is the condition for survival in the modern reality. Social transformations occurring in the process of formation of a new industry determine new tasks facing all modern education. The emergence of new professions and changing requirements to the competencies of graduates of educational institutions will require readiness to change the meaning and content of education, to introduce new methods and means of education.

Modern requirements to the quality of education, strengthening the importance and development of the content of the course “Physics” in schools of Kazakhstan, increasing the arsenal of hardware and software, electronic educational resources used in modern schools, require revision of the system of physics teacher training and its orientation to the training of a new type of teacher, capable and ready to work in a new information and educational environment (built on the basis of ICT tools).

The teacher of physics of the new generation should be ready to form (develop, transform, adapt) the information and educational environment for mastering by schoolchildren of this or that component of educational content. This is due to the fact that the composition and interrelation of components of the information and educational environment should have a flexible structure and functionality that adapts to the peculiarities of the specific content of the environment (educational content), needs and abilities of individual students.

Analysis and generalization of the results of methodological, pedagogical and methodical research on the problem of training future teachers to use ICT in teaching allows us to conclude that the teacher’s activity not only does not become less important and meaningful, but moves in the new environment to a new, higher level of significance. The research problem consists in the contradiction, the essence of which is characterized by the need to achieve a new quality of education, adequate to the needs of modern society and the state in the educational environment based on ICT, on the one hand, and the lack of a systematically grounded methodological system of training future teachers of physics, capable and ready for effective and fruitful professional activity and achievement of educational results in such an environment, on the other hand.

The need to resolve this contradiction confirms the relevance of the study, in which the author has tried to answer the following question: in what directions is it necessary to improve the system of training future physics teachers to design and organize students’ learning activities in the information educational environment?

2. Literature review

Wang and Woo [1] discusses the integration of Information and Communication Technology (ICT) into teaching and learning. It emphasizes three key areas of integration: curriculum, topic, and lesson. The paper introduces a systematic planning model to guide ICT integration in the topic area, and it includes a sample ICT integration plan. The focus is on practical application, providing educators with a framework for implementing ICT effectively in their teaching.

Aydın and Gürol [2] reflects on the three-decade prevalence of ICT use in education, resulting in a surge of research studies. The review aims to summarize critical factors related to ICT use, using the PRISMA Statement for the review process. The study presents a generic model illustrating ICT-related conditions for students, teachers, and schools. It also suggests future research directions. The emphasis is on summarizing existing literature, identifying trends, and proposing a model to guide further research in the field of ICT in education. The key findings include a positive correlation between the volume of ICT research and the scale of ICT integration programs. It also highlights a lack of subject-specific focus in most studies, with a

call for more attention to subject disciplines. The dominance of higher education contexts in the reviewed studies is acknowledged, suggesting a need for more research in preschool, primary, and secondary school settings. The paper emphasizes a shortage of experimental and qualitative research designs, urging the need for more diverse methodologies. The lack of consensus on the conceptualization of ICT use is noted, advocating for the development of generic ICT use models. The study concludes with a call for future research to focus on innovative ICT use and its impact on student learning.

Akram et al. [3] explores the impact of Information and Communication Technologies (ICTs) on teaching and learning practices in Pakistan. It emphasizes teachers' perceptions, attitudes, and technological knowledge as crucial elements in effective ICT integration. Positive perceptions are highlighted, along with reported barriers such as internet speed, infrastructure, and training. The study recommends clear policies, budget allocation, and career development opportunities for teachers to enhance their technological competencies and facilitate successful ICT integration. Challenges such as teachers' technological incompetence, inadequate resources, and time constraints are identified. The study suggests the need for effective policies, infrastructure, and training programs to support teachers in integrating ICT at all educational levels.

Candido et al. [4] focuses on the teaching of physics using interactive simulations in the context of modern physics. It conducts a systematic literature review from 2002 to 2022, evaluating and summarizing relevant research publications. The results highlight the success of interactive simulation technologies like Java applets and PhET in enhancing students' critical thinking and creative problem-solving skills. The text underscores the importance of teachers, school staff, students, simulation design, and technology in the success or failure of interactive simulation use. Recommendations include providing tutorials and training for educators and ensuring the availability of gadget-friendly simulations.

The authors of these manuscripts revolve around the integration of ICT or technology in education. They discuss practical applications, summarize existing research, present models or frameworks, and provide recommendations for future practices and research directions. Each researcher emphasizes the importance of educators' roles, infrastructure, and positive perceptions for successful ICT integration in teaching and learning. They highlight the need for more diversified research methodologies, including experimental and qualitative designs. Positive outcomes of ICT integration include improved student learning, enhanced teacher competencies, and better communication between teachers and students. The reviews provide valuable insights and recommendations for the research community, practitioners, and policymakers in the field of ICT integration in education.

Studies argue that teacher competence includes knowledge of the type of pedagogy appropriate for implementation in the learning environment and the ability to relate technology to learning content. Successful ICT implementation requires adequate staff with the necessary competencies [5–11].

Teachers who are competent and proficient in the content easily integrate technology into their teaching, which enhances student learning.

UNESCO identifies four key competencies for the successful integration of ICT in teaching: pedagogy, collaboration and networking, social issues and technical issues [12]. The importance of balancing various competencies, including technological, pedagogical and content knowledge, for effective implementation of integrated teaching and learning using ICT is emphasized.

The results of these studies confirm not only the importance of teacher ICT competency, but also the need for an integrated approach that considers the relationship between technology, content and pedagogy for effective learning.

The study analyzed current scientific publications to identify current trends and directions of development in physics teaching, including those related to the use of artificial intelligence.

Yun [13] used the thematic modeling method to identify tendencies in research on physical

education. The study employed topic modeling techniques, specifically the Latent Dirichlet Allocation (LDA) model implemented in Mallet, to extract topics from the abstracts of the collected articles. This methodological approach allows for the systematic analysis and identification of recurring themes and topics within the literature. The study identifies several topics that have gained increasing interest in recent years, including the pedagogical content knowledge (PCK), assessment of student achievement, and the gender dimension in physics education. This suggests a growing recognition of the importance of these aspects in shaping effective teaching and learning practices.

Mahligawati et al. [14] identifies several key themes in the application of AI in physics education, including concept introduction, individualization, social interaction, and assessment. This suggests a multifaceted approach to exploring AI's role in enhancing various aspects of physics learning. The findings highlight the positive impact of AI in enhancing conceptual understanding, providing personalized instruction, promoting social interaction, and improving assessment methods in physics education. This indicates the potential of AI to address various challenges in traditional teaching methods. The paper also identifies challenges associated with implementing AI in physics education, including technical infrastructure, teacher training, data privacy, and ethical considerations. This suggests a realistic assessment of the limitations and obstacles to integrating AI into educational practices.

Jho [15] provides a comprehensive overview of how AI technologies such as predictive analytics, adaptive learning, natural language processing, and computer vision can be leveraged to address contemporary challenges in physics education, paving the way for more effective and engaging learning experiences in the future.

3. Research methodology

Foresight automates and streamlines the exploration process. It achieves this by presenting users with “guideposts”, which are visualizations corresponding to pronounced instances of statistical descriptors of the underlying data, such as strong correlations, skewness, concentration, or clustering [16].

These guideposts serve as starting points for exploration, allowing users to quickly navigate through the dataset without being overwhelmed by the sheer volume of data attributes and visual encodings. Users can further refine their exploration by issuing “guidepost queries” containing constraints on metric type, strength, attributes, and values, enabling them to explore the network of guideposts efficiently.

Additionally, Foresight provides global visualizations of ranking-metric values for each descriptor to help orient users and ensure thorough exploration. It facilitates interactive exploration through fast, approximate sketching to compute ranking metrics, enhancing usability and efficiency.

Foresight is a visualization recommender system that leverages statistical descriptors to guide users in exploring large datasets, offering an intuitive and efficient approach to exploratory data analysis.

Considering educational activity as a social process, where the qualitative result is significant for all stakeholders of education, in this study we used the methodology of rapid foresight.

Rapid foresight is a strategic planning technique that involves rapidly anticipating future trends and changes. In the context of teacher education, involving students in this process can provide valuable information and perspectives.

The study involved a total of 12 students who participated in a collaborative and iterative process of identifying key areas for improving teacher preparation. The purpose was to use the ideas and perspectives of these students to identify areas for improving teacher education.

The twelve students who participated in the study were enrolled in a Modern Learning Technologies course. This group utilized a rapid foresight approach that included activities

such as focus group discussions, brainstorming sessions, and collaborative workshops. The methodology aimed to gather diverse opinions on emerging trends in education and technology and to envision potential future scenarios.

4. Results

Foresight research technology has become an essential element in the field of forecasting the future. The main idea of this technology is the joint creation by all participants of a foresight session of a so-called time map, which is formed on the basis of their work with images and schemes. This technique is particularly effective in training young people, since this group is characterized by the perception of visual images rather than texts. Specialists express their preferences in relation to certain initial trends and the most outstanding development ideas, on the basis of which sets of maps of probable events and technologies are created. “Map of the future” – a visual representation of the overall future, including key trends, events, technologies, strategic crossroads and decision points in the educational sphere, becomes the final product of the foresight session. Thus, unlike other methods of forecasting and planning, the result of a foresight session is a “map of the future” created on the basis of the opinions of its participants.

Structurally, the map of the future is a table placed on a large sheet of paper for better visualization. It contains three columns corresponding to three event horizons: near, medium and long-range. Each time horizon spans 5-10 years, where the near horizon covers 5 years, the middle horizon covers 10-15 years, and the long horizon covers 15-20 years. With the participation of the moderator, participants place cards on the map of the future, such as trends, technologies, opportunities, threats, etc. Gradually an image of the future is formed, which is projected within the framework of the foresight session.

This rapid foresight study included the following steps in the course of the group work (conducting the session):

4.1. Defining the object, subject and boundaries (frame) of the future map

The task of this tact is to clarify the subject of the work, the focus of attention, the boundaries of consideration of the subject (topic of discussion). The topic of discussion of the foresight session was “Information technologies in physics lessons”.

4.2. Trend field formation

The task of this tact is to create a description of the environment, directions and dynamics of its change, as well as the factors affecting it.

The essence of work during the tact is to place on the map of the future “trends” – the main trends increasing or decreasing their influence on the subject area.

The field of information and communication technology in learning is constantly evolving and changing. The main trends identified by the participants were:

- The growing popularity and accessibility of online education. A variety of courses, webinars and distance learning platforms allow learners from different parts of the world to receive education from the comfort of their own homes.
- Increased interest in hybrid learning. Students can access online learning materials and resources and attend classes at schools.
- The increasing need to use machine learning algorithms to personalize learning. Adaptive learning platforms analyze each student’s progress and needs to offer individualized assignments and materials.
- Development of mobile devices and applications. Students can access educational resources anytime and anywhere.

- Growing interest in virtual reality (VR) and augmented reality (AR) technologies. They allow students to immerse themselves in virtual worlds and visualize complex concepts.
- Lack of equipment and access. Some educational institutions may have limited access to modern equipment and technological resources, creating inequalities in the use of information technology.
- Insufficient training of teachers. Some teachers may have difficulty integrating information technology into the classroom due to lack of training or lack of time to learn new methods.
- Increased use of technology can raise concerns about data security, privacy, and access to inappropriate content.

These trends demonstrate how modern technology is changing the way we learn and providing more opportunities to access education in different formats.

4.3. Formation of the field of subjects

The task of this tact is to define the list of participants operating in the space of the foresight object and topic.

Subjects identified by the participants: students, teachers, parents, school management.

4.4. Identification of threats and opportunities

The task of this tact is to identify and understand realistic and plausible situations that either open windows of opportunity for them or destroy the possibility of existence and action in the given foresight space.

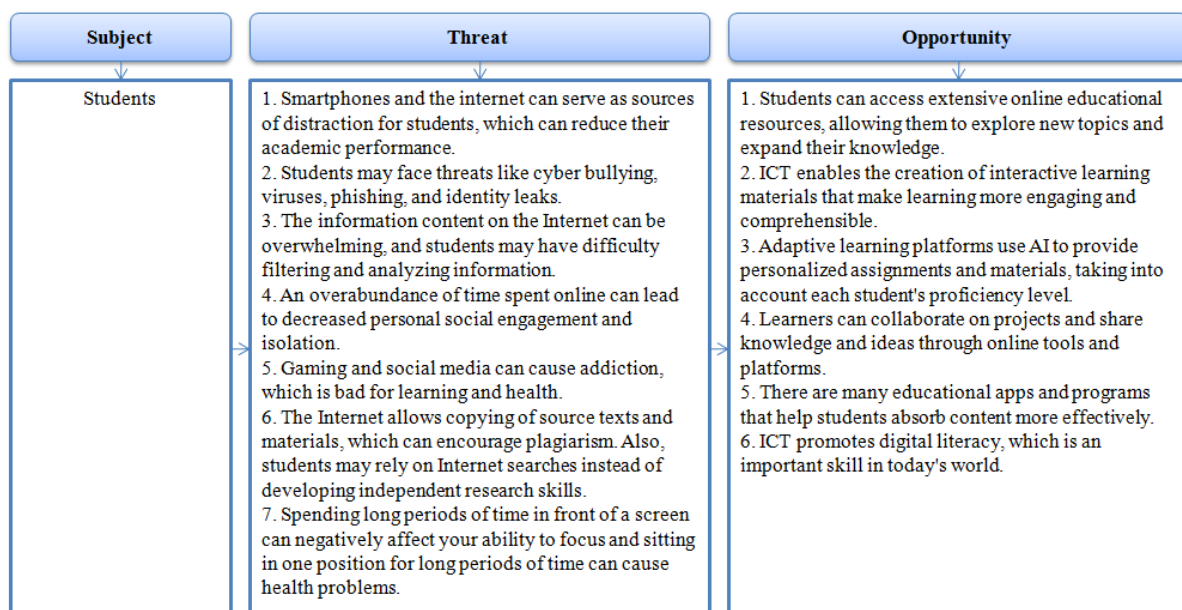


Figure 1. Threats and opportunities, part 1.

4.5. Filling the future map with content: regulations, formats, technologies

The task of this tact is a detailed saturation of the described environment (foresight object) with elements of activity and understanding of how exactly this activity is realized.

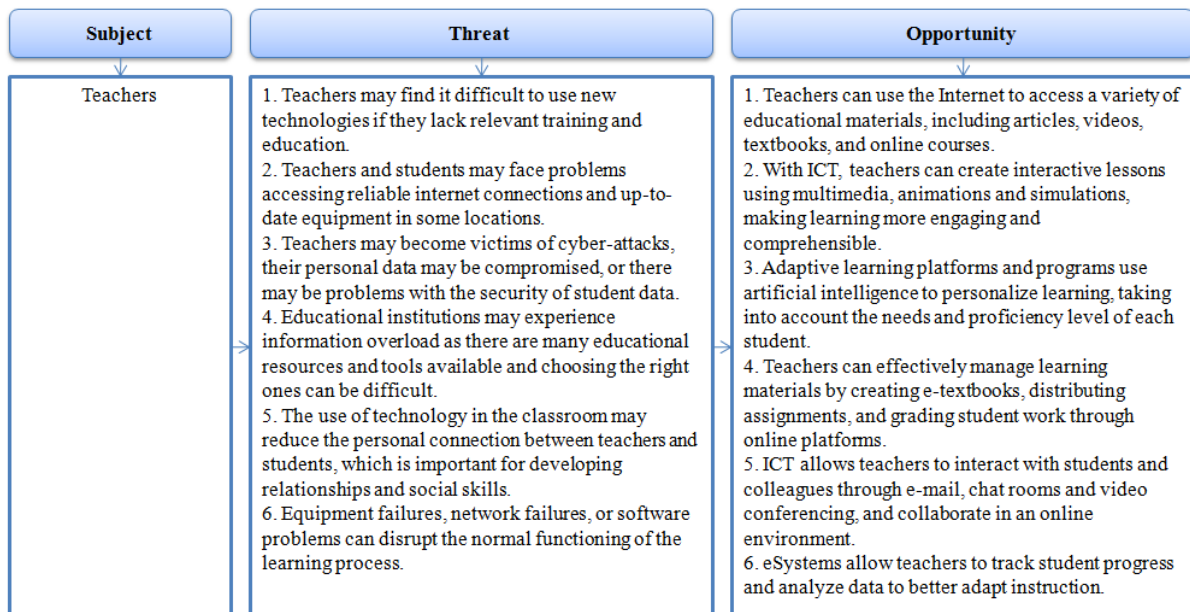


Figure 2. Threats and opportunities, part 2.

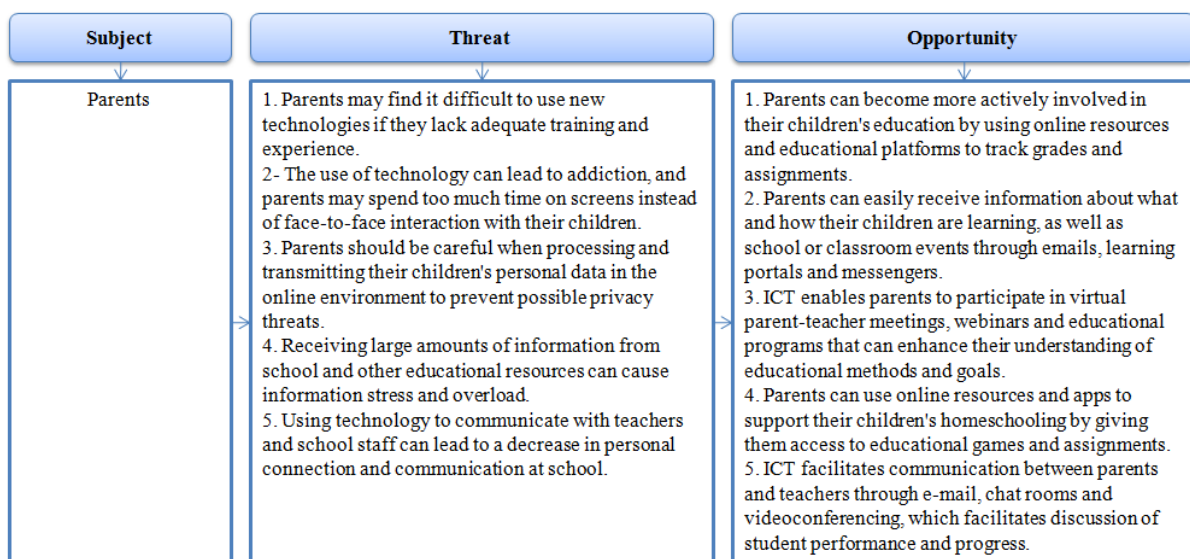


Figure 3. Threats and opportunities, part 3.

The format in rapid foresight is understood as a way of organizing communication between subjects: who, with whom, about what and on what principle organizes joint activities.

ICT-enhanced learning formats can be adapted to meet specific educational goals and needs, and their choice depends on the context and learning objectives.

For example, online courses allow students to learn subjects and topics through interactive materials, video lectures, exercises, and tests available online. Platforms such as Coursera, edX, and Udemy provide a wide range of online courses in a variety of subjects.

Distance learning provides learners with access to learning resources and materials and the

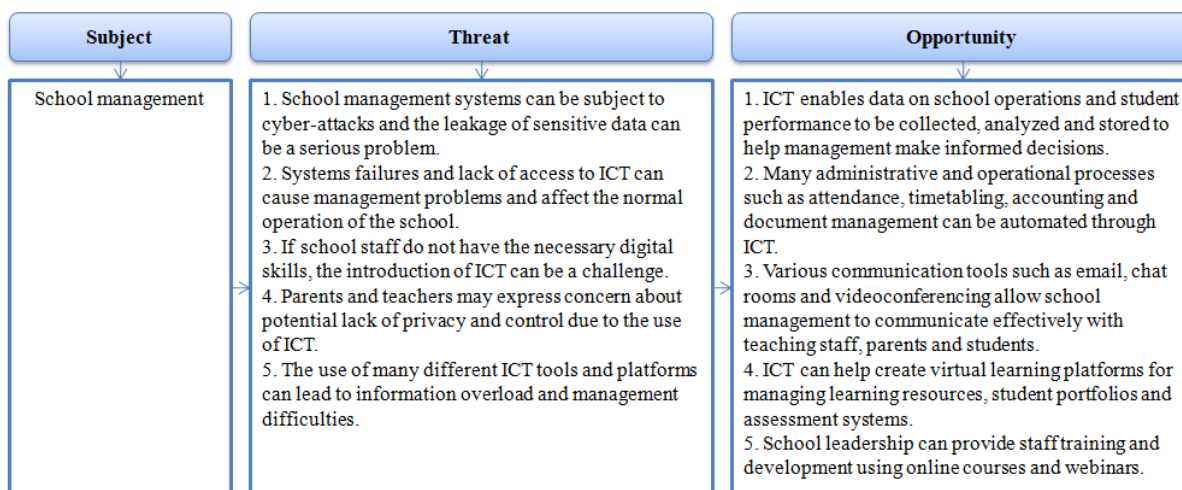


Figure 4. Threats and opportunities, part 4.

opportunity to learn anywhere and anytime. This can be organized using learning management platforms, e-textbooks and videoconferencing.

Learning using mobile devices (smartphones and tablets) allows learners to study materials and complete assignments anytime and anywhere. This can be realized through mobile applications and mobile versions of learning platforms.

Webinars and videoconferencing allow teachers and students to interact in real time, discuss content and solve problems. Platforms such as Zoom and Microsoft Teams provide tools for online meetings.

Creating educational communities on social media and forums allows you to discuss topics, ask questions and share knowledge and experiences with other students and teachers.

Technology is a single technological solution or a package of technological solutions significant for the development, discovery or extinction of a particular trend or format.

The use of information and educational resources at physics lessons can significantly enrich the learning process and make it more interesting and understandable for students. Information and educational resources that were highlighted by the participants of the foresight session:

1. Electronic simulations and virtual laboratories allow students to experiment with physical phenomena and processes without the need for physical equipment. Examples include PhET Interactive Simulations and Labster.
2. The teacher can provide video lectures or video lessons on specific topics in physics. This helps to visualize abstract concepts.
3. Using presentations with interactive elements such as animations, embedded videos and hyperlinks can make a lesson more appealing and understandable.
4. There are many educational websites and resources dedicated to physics. For example, websites of universities, scientific journals, and problem-solving and knowledge-testing platforms.
5. E-textbooks and interactive resources can include animations, video, audio and other interactive elements that make learning more engaging and comprehensible.
6. Creating educational groups or forums on popular social media sites can facilitate information sharing and mutual support between students and teachers.
7. There are many mobile apps designed for learning physics, including problems, reference books, and interactive games.

8. Data analytics and artificial intelligence systems can provide personalized recommendations and track student progress, helping teachers tailor instruction to individual needs.
9. Gamification involves the use of game elements and mechanics for educational purposes. This can include educational games, quests and competitions.
10. Students can create electronic portfolios in which they save their work, projects, and accomplishments to showcase their progress and learning achievements.

A regulation is a simplified (standardized, regulated) format. An institutional (regulatory) “response to a challenge” is essentially a one-step act of managerial will.

Participants noted the need to develop a cybersecurity strategy, ensure equal access to technology, caution against misuse of technology, and teach students digital literacy.

4.6. Shaping the image of the future

In conclusion, the participants of the foresight session formed an image of the future that meets the expectations of the group.

The use of information and communication technology in the classroom will continue to develop and evolve in the future.

First, increased use of virtual and augmented reality. Teachers will be able to create virtual labs and field trips for deeper understanding of the material.

Second, the use of artificial intelligence and adaptive learning.

Third, the development of more interactive and multitasking educational applications will allow students to interact more actively with the learning material and create their own projects.

Fourth, the trend towards distance learning and flexible lesson formats will continue. Teachers and students will have access to educational materials and resources from anywhere in the world.

Fifth, connected devices and IoT technologies can be used to create smart classrooms and improve the management of learning resources.

Sixth, blockchain technology can be used to validate and store educational achievements and diplomas, ensuring the authenticity of educational data.

Seventh, online collaboration platforms and tools will continue to evolve, allowing students and teachers to collaborate in real time regardless of distance.

Eighth, artificial intelligence-based virtual teachers and learning assistants will provide students with additional support and feedback outside of the classroom.

Ninth, ICT will be used to improve the assessment process and analyze data on student progress, allowing for more accurate adaptation of the educational process.

Tenth, an important aspect of the future use of ICT in the classroom will be an increased focus on ethics and cybersecurity to protect students’ personal data and support the ethical use of technology in education.

5. Discussion

The trends identified by the participants will shape the future use of ICT in the classroom, making education more interactive, accessible and personalized for students.

Therefore, teachers of the future must develop a variety of key competencies to be competitive and effective in a rapidly changing educational environment. Teachers must have the technological skills to use information and communication technology effectively in the classroom. This includes proficiency with computers, software, online resources, and an understanding of cybersecurity principles. Teachers must be prepared for change and ready to adapt to new teaching methods, technologies and student demands. Teachers must foster students’ analytical, evaluative, and critical thinking skills. This enables pupils to understand information more thoroughly and to apply knowledge in practice. The skills of planning, curriculum design, assessment of learning outcomes and effective transfer of knowledge remain

key. Teachers must be prepared to support students' social and emotional development and to foster communication and cooperation skills. Teachers must be able to adapt the learning process to the individual needs and learning levels of each student, using adaptive technologies and methods. Teachers must be able to collaborate with colleagues, parents, and other educational professionals to share experiences and create better learning. Teachers can assume positions of leadership, and for this they need skills in managing, planning, and organizing educational research projects. Teachers must be willing to continually learn and self-develop to keep up with the latest educational trends and technological innovations. Understanding of cultural diversity and the ability to create an inclusive educational environment. Teachers can foster students' creative and critical skills and teach them how to solve problems effectively.

Teachers who possess these competencies will contribute to a quality and up-to-date education for their students and remain competitive.

6. Conclusion

The pedagogical study employing the foresight method yielded insightful results by gathering diverse opinions on new trends in education and technology. The study involved participants from various educational backgrounds, and the foresight method facilitated a forward-looking exploration of emerging trends. Here are the key findings:

- The foresight method successfully identified and cataloged a range of emerging trends in both education and technology. Participants contributed their perspectives on innovations, methodologies, and technologies shaping the future of education.
- The study highlighted the richness of opinions among participants, reflecting the diversity of experiences and backgrounds. This diversity contributed to a comprehensive understanding of the multifaceted landscape of educational trends.
- Through foresight activities such as scenario building and trend analysis, the study provided insights into evolving pedagogical approaches. Participants shared views on how teaching methods might adapt to integrate emerging technologies and pedagogical theories.
- Participants discussed the impact of technological advancements on learning environments. Insights included perspectives on the role of virtual reality, artificial intelligence, and collaborative online platforms in shaping the educational landscape.
- The study examined potential implications for educational institutions, including changes in curricula, teacher training, and the overall structure of educational programs.
- The foresight method revealed a growing emphasis on student-centric approaches, with participants expressing the importance of personalized learning, adaptive technologies, and inclusive educational practices.

In conclusion, the pedagogical study using the foresight method successfully captured a spectrum of opinions on new trends in education and technology. Further research will focus on the following aspects: how future teachers' participation in a foresight study analyzing trends in physics teaching affects their academic achievement and future professional activities in education. What are the influences of discussing these issues on students participating in focus groups? Further research in these areas will further our understanding of the impact of educational research in shaping future teaching practices and educational strategies. The findings provide valuable insights for educators, institutions seeking to navigate and adapt to the dynamic changes in the field of education.

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Online control of educational results of the unit “Electricity” in the conditions of blended learning

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Abstract. The article describes the technology of online control of educational results of the unit “Electricity” in the conditions of blended learning. It was determined that during the online stages of studying unit “Electricity”, reverse communication is an urgent issue when receiving information in a distance format, and online control is designed to support the organization of a modern training session. Three topics have been singled out in the unit, in the context of which it is appropriate to develop control measures. Topic I “Electric Field in a Vacuum” focuses on the study of electric field strength, potential, the relationship between strength and potential, the electric dipole, and the circulation and flow of an electric field. Topic II “Electric Field in a Substance” involves the study of the electric field in dielectrics and conductors in an electric field. Topic III “Electric Current” includes general laws of electric current, electric circuit, current in a circuit with a capacitor, and current work and power. There are outlined the different types of tests: graphical, calculation, animated, audio that form the means of online control in the context of the outlined unit. The developed technology of online control of educational results of the unit “Electricity” provides for an organic combination of the presentation of educational materials with control measures. The research methodology involved the analysis and synthesis of scientific, pedagogical, methodological sources and empirical methods, as well as the analysis of the obtained results. Before the introduction of the developed technology and after the completion of the experimental work, a study was conducted, which included an analysis of the quality of knowledge when studying the specified topic. The obtained results before and after the experiment were tested using the Pearson statistical test χ^2 .

1. Introduction

In connection with the pandemic [1] and the introduction of martial law in Ukraine [2], there is a need to modernize the education system. The practice of using blended or distance form of learning dominates [3,4]. Forms and methods of education are being improved, new technologies for learning and providing educational content are emerging [5,6]. In particular, during studying the unit “Electricity” in the context of studying of discipline “Physics”, there is the need in assessment of its quality. This applies both to the assessment of the level of knowledge, skills and professional competences of students, and to the quality of the educational services provided to them in the context of electrical engineering education.



Both the organization of the educational process and the quality control of education remain the subjects of numerous studies and discussions [7, 8]. During remote stages of electrical engineering education, reverse communication when receiving information in an online format becomes an actual issue. Also, it is necessary to be noted that any submission of information must be monitored for assimilation by the higher education applicants. The main requirement for control measures of the activities of higher education applicants is the professional focus of monitoring in the conditions of distance learning. In order to achieve the objectivity of control in the conditions of distance learning, the requirements of informativeness, validity and reliability of control, differentiation of verification should be followed.

The aspects of distance and blended learning are being investigated with by many scientists, in particular research on the impact of distance and online learning [9,10]. Researchers investigated distance learning quality assessment [11], there were considered perceptions of distance learning during the COVID-19 pandemic [12]. The scientists investigated the impact of video conferencing during emergency distance learning [13]. Also there were examined the technology and instructor dimensions and academic performance of distance students [14]. The evaluation of the distance learning combining webinars and virtual simulations [15,16] and the problem of professional training of electrical engineers is widely studied in pedagogical theory [17].

Over recent years, theorization of energy democracy has brought additional nuance to practice-based imaginaries and associated definitions theory [18]. The authors note the need to study different aspects in the energy sector [19,20], current issues of modern electricity generation [21], production of electricity from renewable sources [22]. The researchers take into account that the studying of the specialists in the field of electrical engineering is conducted on the basis of many years of experience in the construction and operation of electricity consumption systems, the experience of the world electricity industry, and the modern computer technologies [23]. The issues of control and monitoring during distance learning are devoted to works [24–26]. Labour market needs for engineers with enhanced knowledge in electrical engineering and renewable energy [27]. Innovation of engineering teaching methods based on multimedia assisted technology is covered in works of some authors [28]. The scientists in the studies focuses on applying knowledge engineering techniques in control engineering education [29]. The researchers analyze some aspects of quality control and efficiency of electronic educational and methodological complexes of educational disciplines usage in the educational process [30,31]. The investigation considers the problem of an interface for educational platform, which is fully effective for achieving the outcomes of educational activity [32]. There were investigated the learning tools of informational and educational environment [33], application of 3D models of electrical engineering in the performing laboratory work [34], but the technology of online control of educational results of the unit “Electricity” in the conditions of blended learning was not the specified subject of the study.

The aim of the article is to develop of technology of online control of educational results of the unit “Electricity” in the conditions of blended learning.

2. Methods

The research methodology involved the analysis and synthesis of scientific, pedagogical, methodological sources and empirical methods, as well as the analysis of the obtained results. Learners in the experimental group studied the topic with only one control measure, while in the experimental group a system of control measures was offered. The implementation of the technology of online control of educational results of the unit “Electricity” in the conditions of blended learning was provided by a system of tests of various types (graphical, calculation, audio, animated) and control work, which involved solving problems and presenting them in the online education system. The study of the unit “Electricity” in the conditions of blended learning involved the use of a quiz, complex tests and the final test. The study of the topic

“Electricity” was accompanied by an online course. Before the implementation of the developed technology and after the completion of the experimental work the study was conducted. It included an analysis of the quality of knowledge of studying the specified topic. The obtained results before and after the experiment were tested using the Pearson χ^2 statistical test [35].

3. The implementation of technology of online control of educational results of the unit “Electricity” in the conditions of blended learning

During the organization of the educational process, the tutor must take into account the purpose, content, means of pedagogical communication, his role and the role of students in the pedagogical system, functions, types and methods of control. Systematicity is associated with a variety of forms and methods of control.

Blended learning in this study will be understood as a flexible learning technology, which consists of a combination of classroom learning and tasks in the online environment. Auditory work is accompanied by control in the classroom, and non-auditory work is accompanied by online control with the help of learning tools, including test control, which includes various types of tests, modular and final estimation measures, which include the performance of problem tasks. Online control within the framework of extracurricular work of students may involve various types of tests, assignments and monitoring of learning activities in the online environment. There are outlined the following types of test questions that form the complex and final test according to the proposed technology: graphical, animated, audio and calculation. There are presented the examples of the different types of tests in the context of the unit “Electricity” (figure 1).

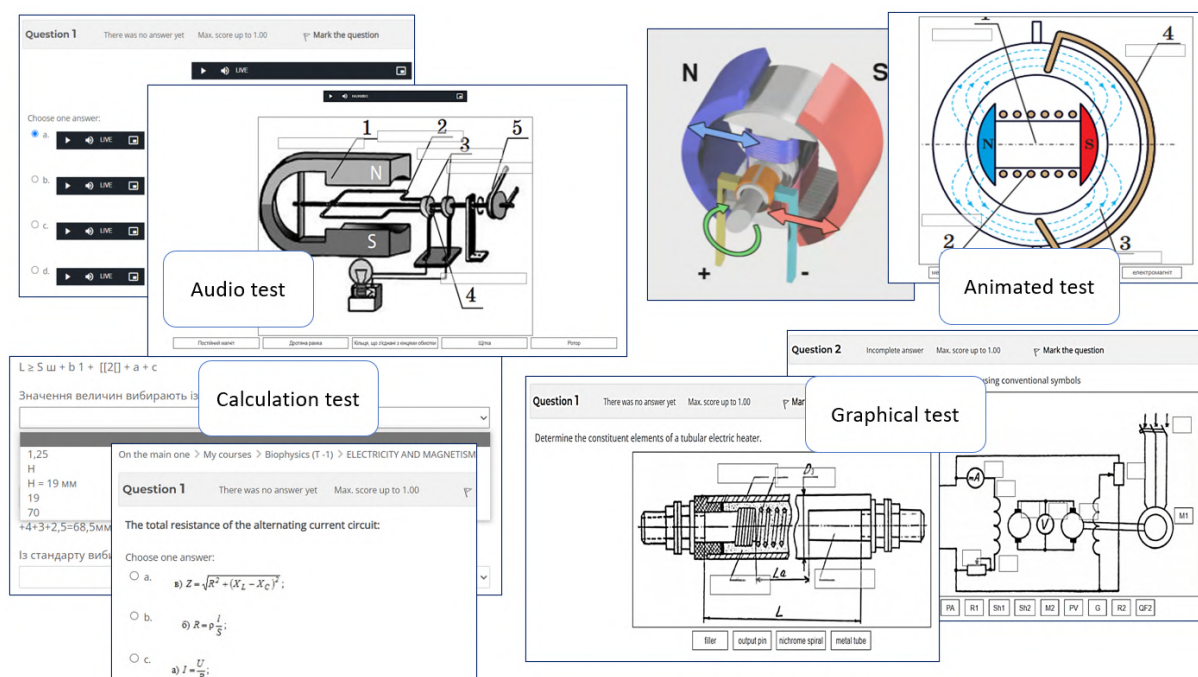


Figure 1. The examples of the different types of tests in the context of the unit “Electricity”.

The calculation tests can vary in complexity and may cover different areas of science. The purpose of a calculation test is to measure a person’s numerical reasoning skills, problem-solving abilities and mathematical fluency. The student must compute, then input the numerical response. With the use of the following type of tests, applicants of higher education can improve

their speedy calculation skills as well as their understanding of the theoretical, technical, and mathematical domains.

The audio test is a control measure that involves fixing the level of knowledge acquisition at a given interval of mastering educational content. The essence of the audio test is that the student has the opportunity to listen to an audio question and options for possible audio answers to this question. After listening, the student chooses the correct answer. Audio tests are relevant in the educational process due to the fact that modern students prefer audio files to text and even video files. Therefore, the development of this type of test tasks must necessarily be accompanied by modern audiovisual content. The use of this type of test tasks prevents mechanical selection of the answer, activates memory and the degree of assimilation of educational content. Therefore, in the context of online control, the use of audio tests is relevant.

The usage of a graphical test aims to develop professional competences through the training of visual perception and work with engineering drawings, diagrams, and other graphic objects in the conditions of blended learning. This type of test offers a chance to deepen awareness of certain processes and technical systems within the complex, serving as an addition to the theoretical study of teaching materials, practical applications, and laboratory work. Test that allows to drag a visual picture into a text field allows to analyse and distinguish between different types of educational content. A description of graphic items, procedures, intricate systems, and engineering machine components is provided for the work. Student should examine the suggested objects and graphic images, then put together the description and the matching graphic image. These tests can help with analytical skill development, memory training, and visual perception training. The goal of the graphical test is to help students develop their ability to perceive engineering items visually.

Based on a plane or spatial representation, graphical test allows users to move words to a graphic image. The visual tools have been carefully chosen, and they feature pertinent sections that could be explained in a classroom. Text explanations offer a way to bring up information about the aspects of the suggested visual image.

The logical visualisation of plane or spatial figures and the integration of their constituents are the main objectives of the graphical test for dragging images to images. It is possible to drag the elements to the appropriate area of the drawing with the task of studying the physical processes or complex components of the electrical equipment. Thus, without the need for specialised equipment, these type of tests allow for the development of practical skills as well as the training of visual memory and familiarisation with the practical aspects.

Based on GIF animation of physical processes, an animated test is presented. It is required to select one of the suggested images in order to restart the entire process. The processes of simulating the physical interaction of solids, the motion of particle, liquid, and gas systems, the simulation of dynamic motion, and the spatial animation of geometric forms may all be seen in animated simulators. Animated training simulators are a great tool for classrooms that lack certain necessary equipment. It makes it possible to carry out physical investigations that need specialised equipment and comprehend their working principles.

There are outlined the structural components of studying the unit “Electricity”. The unit consist of three topics: Electric Field in Vacuum, Electric Field in Substance and Electric Current (figure 2).

Topic I “Electric Field in a Vacuum” focuses on the study of electric field strength, potential, the connection between strength and potential, the electric dipole, and the circulation and flow of an electric field. Topic II “Electric Field in Substance” involves the study of the electric field in dielectrics and conductors in an electric field. Topic III “Electric Current” for study includes general laws of electric current, electric circuit, current in a circuit with a capacitor, and current work and power. The technology of online control of educational results of the unit “Electricity” is presented in figure 1.

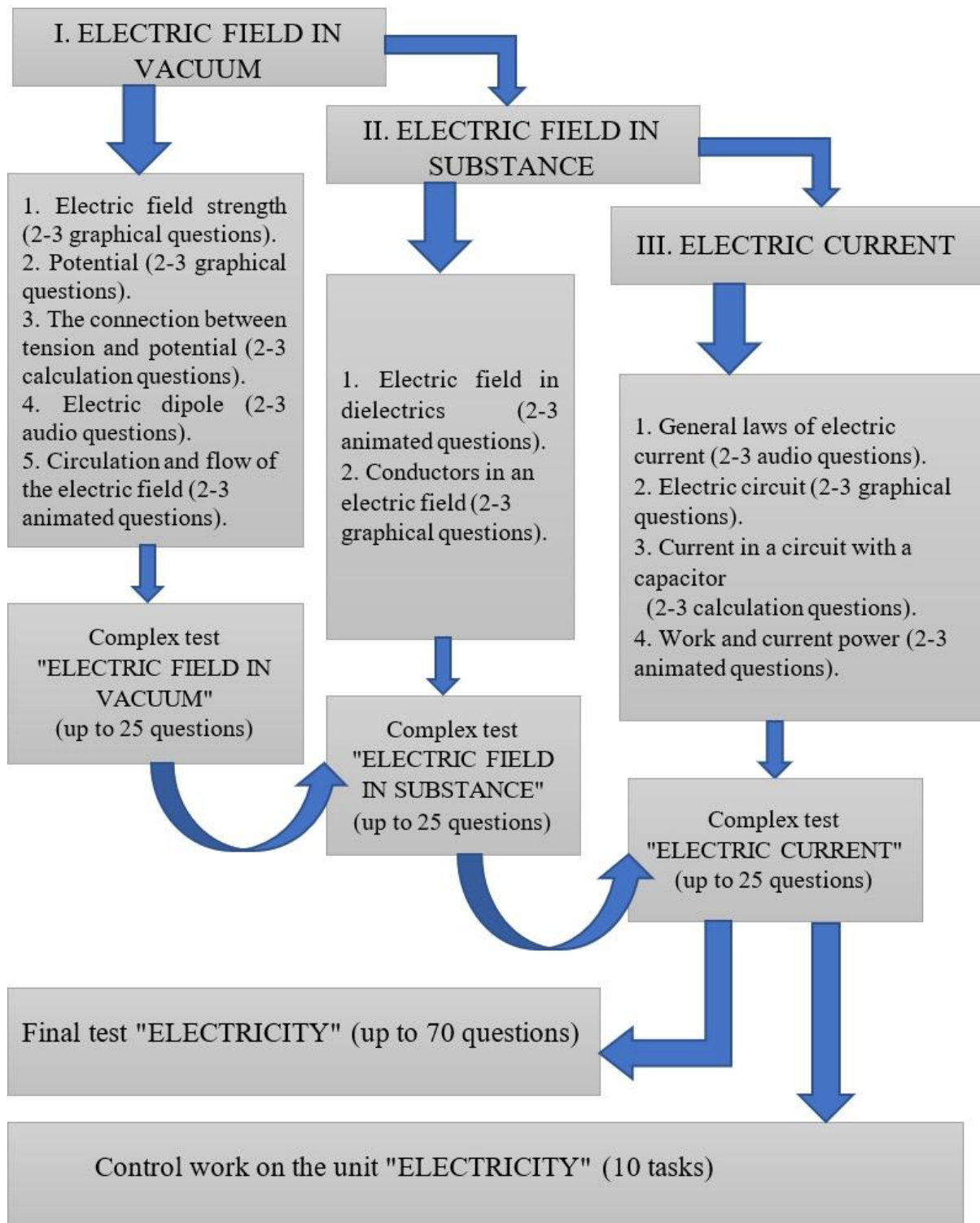


Figure 2. The technology of online control of educational results of the unit “Electricity” in the conditions of blended learning.

There are considered the technology of online control of educational results of the unit “Electricity” in the conditions of blended learning. The study of the topic I “Electric Field

in a Vacuum” involves five control quizzes. For choosing questions for a quiz, there is a need to avoid double interpretations of the answer. The answer to each quiz question should be very specific. It is necessary to select quiz questions of approximately the same difficulty level. It is advisable to offer no more than 2-3 quiz questions for each part of the topic (electric field intensity, potential, relationship between intensity and potential, electric dipole and circulation and flow of an electric field), which makes a total of 10-15 questions. The study of topics II “Electric Field in a Substance” and III “Electric Current” in the conditions of blended learning also involves quizzes. Accordingly, for the second topic, there is a need to make 4 to 6 questions for aspects such as the electric field in dielectrics and conductors in an electric field. For the third topic – 8-12 questions in the field of general laws of electric current, electric circuit, current in a circuit with a capacitor and work and power of current.

After each topic, higher education applicants are offered a complex test containing no more than 25 questions. In the context of making test, the requirements are the following: the clear language, short questions that not exceed half a minute, short and concise answer options.

Upon completion of all three topics, the higher education applicant must complete a final test on the unit “Electricity” in the conditions of blended learning and the control work that involves the solution of 10 problem tasks. A fully solved problem requires an abbreviated record, explanations, drawings (if necessary), derivation of the working formula, calculation and answer. Tasks are completed in writing and in the form of a photo report - a single pdf file - sent in the online course system.

The final test can contain different types of questions: multiple choice, matching, include practice questions, both text formulations and audio. The final test is offered for passing in the time allocated by the online education system, at the rate of 1.5 minutes per test task. If the test will contain 70 test tasks, then there is a need to outline such a test with a time of at least 90 minutes. The technology of online control of educational results of the unit “Electricity” in the conditions of blended learning involves an organic combination of presentation of educational material with control measures.

4. Results

In the conducted pedagogical experiment, the effectiveness of the technology of online control of educational results on the topic “Electricity” in the conditions of mixed learning was investigated. The experiment included 431 participants, divided into control group – 215 students and experimental group – 216 students. The study covered three different thematic blocks: “Electric field in vacuum”, “Electric field in substance” and “Electric current”, which included the study of various aspects of electricity. Each of the topics was complemented by a system of control measures, which covered the use of various types of tests and control works, allowing to assess the mastery of the material by students. The purpose of the experiment was to develop and implement technology that allows to effectively organize the educational process, providing high-quality online monitoring of learning results. An important aspect of the experiment was the provision of feedback in the conditions of distance learning, as well as the assessment of the quality of students’ knowledge before and after the implementation of the developed technology. The results were analyzed using the Pearson statistical test, which made it possible to evaluate the effectiveness of the proposed system. It is important to note that during the analysis of the results, not only the impact of the proposed technology was taken into account, but also the methods used in the learning process. Such an approach to the research made it possible to comprehensively evaluate the effectiveness of blended learning, including the organization of the educational process, the use of various forms and methods of control, as well as the role of the tutor and students in the pedagogical system.

There are presented the results of the experimental work in the form of a table. Thus, the levels of studying the unit “Electricity” during online learning in the control (CG) and

Table 1. Levels of studying the unit “Electricity” during blended learning in the control and experimental groups at the beginning of the experiment.

Level	EG,%	EG, n_i	CG, %	CG, n_{i1}	$(n_1 - n_{i1})^2$	$(n_1 - n_{i1})^2/n_{i1}$
A	1.85	4	2.33	5	1	0.20
B	7.41	16	8.37	18	4	0.22
C	17.59	38	13.95	30	64	2.13
D	21.30	46	22.33	48	4	0.08
E	25.46	55	26.05	56	1	0.02
FX	26.39	57	26.98	58	1	0.02
Total	100	216	100	215		2.67

Table 2. Levels of studying the unit “Electricity” during blended learning in the control and experimental groups at the end of the experiment.

Level	EG,%	EG, n_i	CG, %	CG, n_{i1}	$(n_1 - n_{i1})^2$	$(n_1 - n_{i1})^2/n_{i1}$
A	11.11	24	5.12	11	169	15.36
B	19.91	43	14.88	32	121	3.78
C	25.00	54	22.33	48	36	0.75
D	24.54	53	22.33	48	25	0.52
E	14.35	31	21.40	46	225	4.89
FX	5.09	11	13.95	30	361	12.03
Total	100	216	100	215		37.34

experimental (EG) groups at the beginning and at the end of the experiment are presented in tables 1, 2.

At the beginning of the experiment, the empirical value of Pearson’s χ^2 is 2.67.

At the end of the experiment in the control and experimental groups the empirical value of Pearson’s χ^2 is 37.34. It is defined the degree of freedom $\nu = 5$ ($\nu = k - 1, k = 6$). It is defined a critical value for the degree of freedom χ^2_{crit} (11.070; 15.086) for levels of statistical significance $\rho \leq 0.05$ and $\rho \leq 0.01$.

Thus, the obtained empirical value of Pearson’s χ^2 before the experiment is less than the critical value. That is, $\chi^2_{emp} \leq \chi^2_{crit}$, which means belonging to the zone of insignificance. The levels of studying the unit “Electricity” during online learning in the control and experimental groups at the beginning of the experiment do not have significant differences.

The obtained empirical value of Pearson’s χ^2 at the end of the experiment is less than the critical value. That is, $\chi^2_{emp} \geq \chi^2_{crit}$, which means belonging to the zone of significance. The levels of studying the unit “Electricity” during online learning in the control and experimental groups at the end of the experiment have significant differences.

It is obvious that the author’s technology of online control of educational results of the unit “Electricity” in the conditions of blended learning is effective. The result of the implementation of the technology is the mastery of the components of the outlined unit, and the acquisition of high-quality knowledge and skills in electricity.

5. Discussion

Blended learning offers flexibility in terms of time and place of learning, allowing students to access materials and assessments at their own pace and convenience. In subjects like Physics, where hands-on experimentation may be combined with theoretical learning [36], online assessments provide flexibility for students to demonstrate their understanding of electricity concepts at their own pace and convenience [37]. They can access assessment materials and resources anytime, anywhere, which is particularly beneficial in blended learning environments where students may have varying schedules and learning preferences.

Blended learning allows for the integration of diverse assessment methods, including both traditional assessments such as exams and quizzes, as well as innovative online assessments such as interactive simulations, virtual labs and multimedia presentations. This variety ensures that students' understanding of electricity is assessed comprehensively, catering to different learning styles and preferences [38].

This timely feedback is crucial for promoting self-regulated learning and facilitating students' progress towards mastery of the subject. It enables students to identify areas of weakness and seek additional support or resources as needed, fostering a more dynamic and personalized learning experience [39]. Online assessments can provide immediate feedback to students, enabling them to identify areas of strength and weakness in their understanding of electricity. Educational platforms generate valuable data on students' performance, which can be analysed to gain insights into their learning patterns, misconceptions, and areas needing further reinforcement.

Authors and researchers advocate for the use of data analytics tools to inform instructional decisions and personalize learning experiences in the unit of electricity [40,41]. Online assessment platforms often generate detailed analytics and data on student performance, which can inform instructional decisions and interventions. Educators can use this data to identify trends, assess the effectiveness of instructional strategies, and tailor their teaching approaches to better meet the needs of individual students or groups.

Blended learning facilitates the seamless integration of formative assessment (ongoing assessments used to monitor students' progress) and summative assessment (final assessments used to evaluate students' overall achievement) [42]. By continuously assessing students' understanding of electricity throughout the unit, educators can identify learning gaps early on and provide targeted interventions to support student learning [43]. The challenge of online assessment is maintaining academic integrity and preventing cheating. Educators must implement strategies such as proctoring tools, randomized question banks, and plagiarism detection software to uphold academic standards and ensure the integrity of assessment results. Learning environments lend themselves well to the development of critical thinking and problem-solving skills in the context of electricity. Through interactive online activities, collaborative projects, and real-world applications, students are encouraged to apply their knowledge to solve practical problems related to electrical concepts.

Blended learning promotes accessibility and inclusivity by accommodating diverse learners, including those with disabilities or learning differences. Online resources can be designed to be accessible to all students, ensuring equitable access to educational materials and assessments in the unit of electricity [44]. It allows for differentiation and personalized support for diverse learners, including those with special educational needs or English language learners [45]. Educators can provide additional or alternative assessment options to ensure all students have equitable opportunities to demonstrate their understanding of electricity concepts. Blended learning environments offer opportunities for authentic assessment tasks that reflect real-world applications of electricity concepts. For example, students could collaborate on designing and troubleshooting electrical circuits using virtual simulation tools or working on practical projects that integrate theoretical knowledge with hands-on skills [46].

6. Conclusion

Blended learning, which combines traditional face-to-face instruction with online learning components, offers unique opportunities for assessing educational results in the context of studying Physics. Online control of educational results in this context can be highly effective if implemented thoughtfully.

Online control of educational results in the unit “Electricity” within a blended learning context offers numerous benefits, including flexibility, accessibility, diverse assessment formats, real-time feedback, data-driven insights, authentic assessment opportunities, academic integrity safeguards, support for diverse learners, and increased engagement and motivation. However, it’s essential for educators to thoughtfully design and implement online assessments to maximize their effectiveness and ensure they align with the learning objectives and needs of students.

The study confirmed the effectiveness of the proposed technology of online control of educational results in the context of blended learning. The implementation of the proposed technology contributed to the improvement of the quality of students’ knowledge and skills on the unit “Electricity”. The technology made it possible to effectively organize the educational process, combining the presentation of educational material with control measures. The systematic use of various forms of testing and control works contributed to deep learning of the material. The use of innovative methods of online control, including graphic, audio, animation and calculation tasks, ensured high interaction and involvement of students in the educational process, and also contributed to the development of professional competencies. Analysis of the results of the experiment using the Pearson statistical test showed a statistically significant increase in the level of educational results in the experimental group compared to the control group, which confirms the effectiveness of the developed technology.

Prospects for further research are the development of competency-based types of control for the topic “Magnetism” in online courses, which will allow expanding the use of online control technology in other areas of physical and engineering education.

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The use of computer modeling in the educational process based on the example of studying Coulomb's law

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Abstract. The study analyzes computer modeling tools intended for use in educational and scientific contexts. The concept of modeling as a method of research and a teaching tool is examined, the emphasis is placed on computer modeling. It is shown how physical laws, particularly Coulomb's law, can be studied through modeling. The study uses pre-made simulators, spreadsheets, mathematical packages, as well as our own software in Object Pascal and Python. Experimental testing has confirmed the effectiveness of computer modeling in teaching natural sciences. A survey of students and teachers showed interest in further use of simulation tools in the educational process.

1. Introduction

Modern researchers see information culture as the level of development of information relations in society and as a characteristic of people's information activities. Sustainable computer skills are an important component of information culture. Digital competence is the awareness and the use of digital tools in accordance with the needs of personal, professional and social life (for more details, see [1]). Digital competencies include: the ability to search for, evaluate and process information, as well as understand and use data; the skills of using digital tools to communicate and collaborate effectively with others; the ability to create, edit, and integrate digital content in various formats; the ability to identify risks and take measures to protect themselves from digital threats; the ability to use digital tools to solve problems and make decisions [2, 3].

The modeling method is used to study complex processes and phenomena when conducting experiments is costly or impossible [4]. A model is a specially created object that replicates certain characteristics of the research object for the purpose of its analysis, and modeling is a method of recreating the characteristics of the research object in question. Models can be created both from physical objects (for example, wind tunnels for studying aircraft aerodynamics or simulators for flight and automotive training) and from abstract objects that can be represented by mathematical, graphical, symbolic, and conceptual models.



Computer modeling is the process of creating computer programs or objects in computer programs to depict and analyze various processes, phenomena, systems, or objects in an electronic environment. This approach is used to study and analyze phenomena that may be difficult or even impossible to study without the use of computer calculations.

Computer modeling can be used to study a variety of objects and processes, from climate change to the behavior of physical systems or economic phenomena. It allows us to analyze complex relationships and conduct research in conditions where real-world experiments would be difficult or dangerous. The existing capabilities of computer modeling make it possible to consider it as a visual tool for learning through research. This perspective is the rationale for studying the possibility of using computer modeling in educational activities.

The current state of computer modeling in education and research is a fundamental aspect of the development of educational and scientific practices. Given the rapid technological progress, it is not just a tool for visualizing concepts, but also an important component in solving complex problems that arise in the educational and scientific environment.

In education, computer modeling defines an activity-based approach to learning and development. Its use covers a wide range of subjects, from math and physics to the humanities. Virtual laboratories, simulations, and interactive exercises provide an opportunity to create a realistic learning environment where students can experiment, solve problems, and develop critical thinking. This promotes active participation and improves conceptual learning, which is essential for developing a deep understanding of the subjects.

In scientific studies, computer modeling plays a key role in solving various problems and studying complex systems [5]. From simulations of physical processes to the analysis of large amounts of data, this technology allows researchers to analyze complex relationships quickly and efficiently. Modeling expands the possibilities of experiments, allowing the study of phenomena that would otherwise be difficult, costly, or impossible. Thus, the current position of computer modeling in scientific research demonstrates its key role in advancing knowledge and developing the scientific field.

According to Jurakulov [6], physics has a very important place in science. Therefore, physics education should be conducted carefully and effectively. As studies have repeatedly shown, classical teaching models are so ineffective in physics education that the result at the end of the learning process is almost insignificant. Therefore, physics education should be based on models of active learning, the effectiveness and naturalness of which has been proven [6]. Such methods of active learning include the research method, which can be implemented through computer modeling.

The purpose of the study is to analyze the various computer modeling tools available for the study of physics, in particular, for the study of Coulomb's law.

2. Literary review

Modeling is a complex and multifaceted activity that requires certain knowledge, skills, and abilities. Nevertheless, it is not only advisable to use modeling for familiarization, but also to actively use it during secondary education. Teachers need to be trained for such activities, and the study by Velychko and Fedorenko is dedicated to this process for future computer science teachers [7]. The authors concluded that the content area "Modeling" in a school computer science course is used to develop algorithmic and structural thinking, to develop the ability to analyze various processes and phenomena and find out their cause-and-effect and structural relationships, to determine the sequence of actions to be taken to solve certain problems. Therefore, the preparation of future computer science teachers to teach this topic should be formed during the study of this section on certain educational components, including the educational component "Programming".

The study by Kaydan and Melnichuk highlights the process of creating conditions for

improving and enhancing the results of the educational process through computer modeling in secondary school physics lessons using the MathCad system [8]. The authors claim that with the help of computer modeling in secondary school physics lessons using the MathCad system, we are able to solve most of the problems that arise in the learning process, such as the use of advanced information technologies; the change of forms of education and activities within one lesson; making it easier for the teacher to prepare for the lesson and involve students in these activities; the expansion of opportunities for illustrative support of the lesson, presenting physical processes in the form of graphs, etc.; the implementation of individual work; the implementation of integrated lessons that strengthen the links between subjects; the organization of interactive forms of control of skills, abilities and knowledge; the organization of research, independent, creative work at a fundamentally new level with the possibility of access to the global information space.

Bilousova et al. [9] addressed a similar issue in their study using GeoGebra as a modeling platform. A complex was developed for in-depth study of mathematics. The models in the developed complex are grouped into three sections. The first group consists of models that allow potential students to learn the basic essential mathematical concepts (objects). The second group is focused on the realization of transdisciplinary connections between mathematics and other subject areas. The third group covers models that provide solutions to real-world problems based on model research.

The general issues of creating a model for computing in physics education are addressed by Phillips et al. [10]. The researchers note that despite its disciplinary importance, the integration of computing in physics education remains a challenge and, moreover, tends to be viewed in a narrowly focused way. The authors extend the Physics Education Research concept of computing by constructing a metamodel as a model of modeling that provides insights into computational modeling from the perspective of philosophy of science and previous achievements. The metamodel is formulated in terms of practice, what physicists do, and how they inform each other. The authors implement the developed metamodel in the educational environment, through the production, creation of collaborative physical and digital artifacts designed to promote students' free will, creativity and self-expression along with the study of physics.

The importance of graphical modeling as an important stage in solving a physical problem is shown in the publication by Lymareva et al. [11]. The authors note that the problem of visualizing input information during the study of physics is a significant didactic problem. The solution to it lies in the need to teach students to process different types of graphical information as efficiently as possible, to combine them with each other, to represent physical phenomena and processes in a graphical form (create physical models) and to use visual information to find answers to questions.

Dron studied the formation of research competencies in students during computer modeling of physical phenomena and processes in distance learning [12]. The author came to the conclusion that independent modeling of physical phenomena and processes in distance learning allows students to deepen their understanding of the basics of the studied natural phenomena and processes, the principle of operation and structure of modern technology by visualizing processes with different parameters of the physical model. In addition to high rates of qualitative learning, students' interest in studying the subject increases, which opens up wide opportunities for independent work, promotes the development of creative activity, the formation of research competencies, stimulates the acquisition of additional knowledge and its consolidation, which makes it possible to educate a well-developed personality with the skills of the 21st century.

The study of the modeling method as a means of forming information and analytical competence in the study of physics is covered in the publication of Isycho and Guryevska [13]. Comparing the use of the modeling method and the structural and logical scheme of the

formation of scientific knowledge and the processes leading to the formation of information and analytical competence, we can conclude that when using the modeling method in the study of physics, all components of this competence can be formed in higher education students.

Methodical features of educational modeling of physical phenomena based on the example of implementing the model of oscillation of a system of coupled oscillators and the model of frequency interaction of two oscillators are studied by Holovina and Holovin [14]. To implement the models, the Python programming language is used with the use of the specialized Visual library. The author emphasizes the powerful influence of the model approach on the quality of natural science education. It is noted that this approach contributes to the formation of causal, abstract and logical, materialistic thinking. It contributes to a comprehensive vision of physics, mathematics and computer science as one closely connected structure of knowledge, in which each component carries its own meaningful load.

In STEM education [15], there is an activity pattern such as “design, make, explore”. How to build learning activities based on this principle is shown in the publication by White [16]. This study describes research activities very closely, but in slightly different terms. Nevertheless, it is useful for understanding the necessary direction of building learning activities that will result in preparation for research of objects of any nature.

Advanced research on the problems of using simulation in the educational process has been considered at the international workshop Computer Simulation in Education since 2005. In 2021, a review of the results of the workshop was published by Kiv et al. [17]. In 2022, the review was completed by Papadakis et al. [18].

3. Theoretical background

Computer modeling is a method of solving the problem of analyzing or synthesizing a complex system based on the use of its computer model. This method is based on the fact that an existing model is used to find qualitative and quantitative results, the main requirement for which is the ability to reflect the main factors and mutual relations characterizing real situations, criteria and, if any, limitations [19].

A computer model is an information model implemented with the help of a computer. Meanwhile, information models, along with gnosiological and semantic models, are abstract (ideal) models that describe research objects using a certain language. In this case, abstractness means that it is logical concepts, such as diagrams, graphs, algorithms, equations, etc., that are the components of the model, not physical elements. The very essence of creating such models is to establish certain dependencies between groups of parameters of the object under study [20].

The actual implementation is performed using various tools. For this purpose, you can use a variety of instrumental software tools and environments (MathCad, MatLab, Maple, VisSim, Genius, etc.). The advantage of using mathematical packages is that they can be used as ordinary calculation tools, tools for simplifying expressions, and tools for generating graphics and sound. The means of interaction with the Internet, which are realized by generating HTML pages directly in the process of calculations, have also become widespread.

A qualified user who knows at least one of the programming languages can create the required program or even a whole set of programs independently. However, this approach usually requires a lot of labor to program, debug, and test each program, so to save time, it is advisable to use the specified application software packages, the areas of application of which largely overlap.

The next option is software packages for simulation modeling. Simulation modeling is a research method when the system under study is replaced by a model that can describe the real system with sufficient accuracy. And this model is used to conduct the necessary experiments, the purpose of which is to obtain information about this system. This type of modeling is used when it is not possible to experiment on a real object, build an analytical model, or create a simulation and track the behavior of the system in real time. This type of modeling is the

most effective when designing and analyzing production systems, determining requirements for equipment and communication network protocols, modernizing various processes in the business field, etc. The most popular simulation modeling packages are: Arena by Rockwell Automation, AnyLogic by XJ Technologies, GPSS World by Minuteman Software, Process Charter 1.0.2 by Scitor, Powersim 2.01 by Modell Data AS, etc. The packages differ in the style of modeling, i.e., the environment with the help of which models are created: in Process Charter, the model is built using flowcharts, Powersim and Ethink use the System Dynamics notation system, and Extend uses component blocks.

Given the need for qualified specialists in various fields of modern production, it is advisable to involve computer-aided design (CAD, computer aided design) systems in the educational process. These systems allow for the design of technological processes with less time and money spent and an increase in the accuracy of the designed processes and processing programs. CAD technical support is based on the use of computer networks and telecommunication technologies, personal computers and workstations, and mathematical support is characterized by a variety of methods of computational mathematics, statistics, mathematical programming, discrete mathematics, and artificial intelligence. CAD software systems are among the most complex modern software systems based on the operating systems Unix, Windows, programming languages C, C++, Java and others, modern CASE technologies, relational and object-oriented database management systems (DBMS), open systems standards and data exchange in computer environments. One example is AutoCAD, the best-known of Autodesk's products, a universal computer-aided design system that combines two-dimensional drawing and three-dimensional modeling. AutoCAD speeds up the work of creating plans, increases the speed and accuracy of their execution, and the available visualization tools, such as animation and realistic tinting, allow you to identify shortcomings at the early stages of design.

4. Research methodology

The methods of scientific literature analysis, comparative analysis of software tools and expert evaluation of computer modeling capabilities were used to study computer modeling tools.

The analysis of the scientific literature made it possible to identify the main areas of application of computer modeling in education and science, as well as the potential advantages and limitations of different approaches. A search was conducted in the databases of scientific publications using keywords related to the research topic.

The comparative analysis of computer modeling tools involved consideration of the capabilities of the most common programs, both general and specialized. Functionality, usability, etc. were analyzed. The experts were teachers, physics teachers, pupils and students studying physics.

5. Research results

Computer modeling requires tools that can best investigate the model created. Depending on the complexity and objectives of the model study, these tools can include ready-to-use software simulators, data storage and processing tools (e.g., spreadsheet processors), computer algebra packages, or even custom software. We are studying the process of teaching computer simulation, and therefore it is necessary to consider all of these tools in order to try to formulate the advantages and disadvantages of each.

In order to make the review more substantive, let's define a topic from the school physics course – Coulomb's law.

Simulators that can be used in school physics courses cover a significant amount of educational material. The most well-known collections include [21]: PhET (<https://phet.colorado.edu/uk/>), LabXchang (<https://www.labxchange.org>), Concord (<https://concord.org>), PraxiLabs (<https://praxilabs.com>), Labster (<https://www.labster.com>),

MERLOT (<https://www.merlot.org/merlot/>), Physics at School kit (<https://www.vascak.cz>), etc. They are interesting both for organizing and conducting e-learning and for self-education. The simulations presented here also include simulations for the topic we have chosen (figure 1). It is clear that each simulation represents an appropriate methodological approach to the study of Coulomb’s law. This can be demonstrated on physical devices or on imaginary objects. In any case, the choice of simulation depends on the prevailing teaching technology and the availability and accessibility of simulations for use.

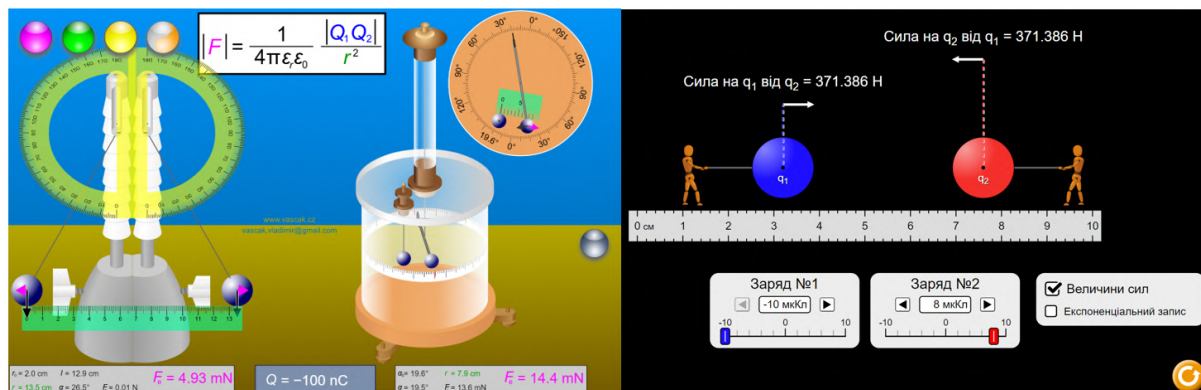


Figure 1. Simulation of Coulomb’s law in the “Physics at School kit” and “PhET” collections.

The analysis allows us to identify some intermediate results. The possibilities must include:

- (i) Realism of the created models. Modern simulators of physical processes make it possible to create very realistic models, reflecting various physical phenomena with great accuracy. This contributes to the faithful reproduction of the real world and allows you to conduct research in conditions that mimic reality.
- (ii) Interactivity and the ability to conduct experiments. Simulators provide an opportunity to study physical phenomena in an interactive environment. Users can change parameters, observe changes, and reproduce experiments without real equipment.
- (iii) Flexibility of model parameters settings. Users can easily customize the simulation parameters to suit their needs and study the impact of different conditions on the results of physical processes.

The existing limitations include the following. First, it is the complexity of modeling. Some physical phenomena can be difficult to model accurately. For example, quantum phenomena are often difficult to account for in simulations. Second, there is cost and resources. Creating high-quality simulations can require significant financial and technical resources. This can present a limitation to access to modern and powerful simulators. Third, there is the need for expertise. To use physical process simulators effectively, users often need to have some expertise in the area under study in order to interpret the results and configure the simulation parameters correctly.

Spreadsheets (or spreadsheet processors) are not only a tool for calculating accounting spreadsheets. Spreadsheets are an excellent all-purpose tool for calculating, storing and analyzing results. They are more suitable than any other application software as a platform for computer modeling. The user can arrange the data they need for research, perform transformations on it, sometimes quite complex ones, implement a computer model, check its response to possible changes in parameters, analyze the results, etc. The main thing when using spreadsheets in modeling is to understand how to implement a computer model.

Spreadsheets are available both as desktop programs and as services. Popular spreadsheets today include Microsoft Excel (Microsoft 365), LibreOffice Calc (LibreOffice), ONLYOFFICE Spreadsheet Editor (ONLYOFFICE), WPS Spreadsheet (WPS Office), and others. The above examples are also available for mobile platforms. Among the cloud services, it is necessary to mention such resources as Google Sheets, Microsoft Excel Online, ZOHIO Sheet, ONLYOFFICE Spreadsheet Editor online and others. Most of them are available under free licenses or licenses with some restrictions. Thus, we can state that there is a significant list of available spreadsheet processors for secondary education and the issue of their availability is not currently an issue. Thus, we can consider the advantages and limitations of using spreadsheet processors in computer modeling. The advantages include:

- (i) Ease of use. Spreadsheet processors such as Microsoft Excel or Google Sheets are known for their ease of use. They have an intuitive interface that allows users to quickly create and edit data. In addition, there is a large number of reference materials that answer a particular question, including in the form of training videos.
- (ii) Calculations and Formulas. Spreadsheet processors allow you to use a variety of formulas and functions to automate calculations. This makes them effective for performing mathematical operations and creating models. It is calculations that we need in order to conduct modeling, study the model by various parameters, and use built-in functions.
- (iii) Flexibility. Users can easily manipulate data, add new columns and rows, sort and filter information, which allows them to quickly change model parameters. Or even create a new model based on the results of previous calculations and research.
- (iv) Easy introduction. In the first stage of learning, solving complex problems is possible without programming, using tasks and copying formulas on the worksheet. This stage is important for step-by-step learning.
- (v) Step-by-step implementation. When solving various problems, a new aspect appears that is critical for mastering the material which is the display of the solution process, not just the final result. This approach allows you to feel how the calculation process is carried out, to study the impact of the argument on the speed of convergence. This helps transform a student from an observer to a researcher.
- (vi) Data visualization. The simplicity of creating charts to visualize the results helps to deepen the understanding of data visualization, provides the necessary experience, stimulates creative search and develops creative thinking.

The disadvantages and limitations of using spreadsheet processors in computer modeling include the following:

- (i) Limited complexity of models. Spreadsheet processors often face a limitation in terms of modeling complexity. They may not be powerful enough for highly detailed and complex physical or mathematical models. However, this limitation in no way affects the use of spreadsheet processors in modeling training.
- (ii) Lack of realistic model behavior. Spreadsheet processors do not always provide a high level of realism in simulations. They may not accurately reproduce complex physical or system interactions. They cannot animate the results, etc.
- (iii) Possibility of errors with large amounts of data. With large amounts of data and complex calculations, spreadsheet processors can be slow and error-prone, especially if a large number of formulas and cell-to-cell references are used, and formulas and data are moved and copied. Potential cyclic dependency of the data.

- (iv) Limited functionality related to the versatility of spreadsheet processors. Spreadsheet processors usually have limited functionality compared to specialized computer modeling tools. This can make it difficult to solve tasks that require advanced functionality.

Here are some examples of how spreadsheets can be used when studying Coulomb’s Law. First of all, we can show in practice what a direct relationship and an inverse relationship are. To do this, it will be enough to calculate the value of the force of interaction between charges at constant values of charges and a variable part of the distance between them. Using the obtained values, we will construct a line graph and demonstrate that the graph will not be a line (figure 2).

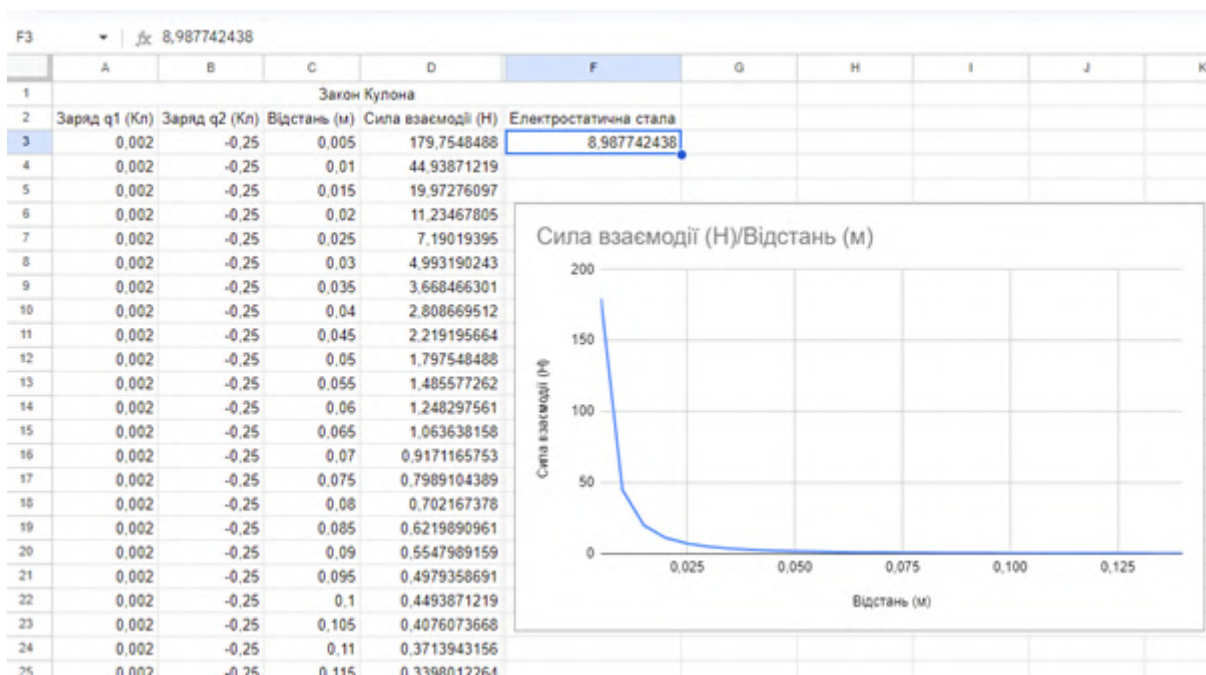


Figure 2. Coulomb’s law in Google Sheets.

Second, we can demonstrate whether the charges will attract or repel at different values. To enhance the visualization, we can use conditional formatting (figure 3)

Computer algebra systems are as useful a tool for computer modeling as spreadsheets. The ability to store data, calculate various values, including through the use of programming elements, built-in functions, and additional modules, make it possible to consider these systems as a full-fledged implementation of a computer model. The available data visualization tools and the absence of a workflow, which is surprisingly important for research, indicate the advantages of computer algebra systems in modeling. The caveats include the need to master the systems at the level of a confident user, since each of them has its own specifics, set of commands, etc. The computer mathematics package Scilab is an excellent tool for conducting research that requires calculations. This package can be applied in our case. Despite the fact that the system, as already mentioned, requires some knowledge, its consideration is already included in the curriculum and relevant textbooks on computer science at the secondary level in Ukraine. We can define either a simple variant of calculating the value of the interaction force according to Coulomb’s law or a more complex variant for an array of values and then experiment with the parameters (figure 4).

Within the framework of academic freedom, each teacher is not prohibited from using not only different methodological approaches to teaching, but also the choice of teaching aids. It is clear

E10 $f_x = \text{ifs}(A10*B10>0; "відштовхуються"; A10*B10<0; "притягуються"; A10*B10=0; "взаємодія відсутня")$

	A	B	C	D	E	F
1	Закон Кулона					
2	Заряд q1 (Кл)	Заряд q2 (Кл)	Відстань (м)	Сила взаємодії (Н)	Напрямок	Електростатична стала
3	0,002	-0,25	0,005	179,7548488	притягуються	8,987742438
4	0,002	0,25	0,25	0,0719019395	відштовхуються	
5	0,002	0	0,005	0	взаємодія відсутня	
6	-2	-3	10	0,5392645463	відштовхуються	
7	-0,0002	-0,25	0,005	17,97548488	відштовхуються	
8	0,00258	0,2658	0,025	9,861552328	відштовхуються	
9	0,002	-0,25	0,25	0,0719019395	притягуються	
10	0,2	-0,3	0,0005	2157058,185	притягуються	

Figure 3. Coulomb’s law in Google Sheets.

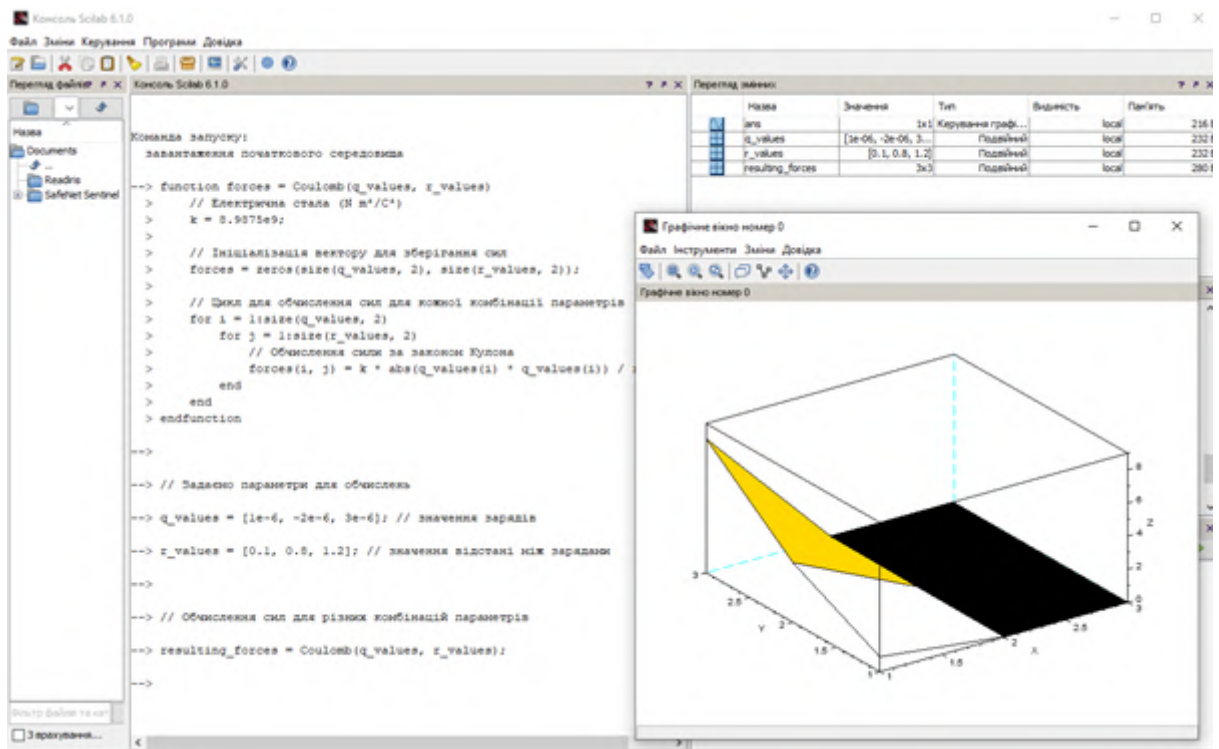


Figure 4. Study of Coulomb’s law in the Scilab package.

that not every teacher will create their own implementations of a computer model, but this is a possibility and should be included in the comparison of computer modeling tools and methods in secondary education. To implement a computer model without using existing general and special-purpose application software, knowledge and experience in programming are required. Moreover, this experience should correlate with the students’ programming experience, because it is one thing to demonstrate the created model when familiarizing the material in general. To provide students with the opportunity to experiment with the implemented computer model, including during self-education activities, is a completely different issue.

In the course of studying the content area “Modeling, Algorithmization and Programming” of the subject “Computer Science”, students are introduced to several programming languages and programming paradigms. Even at the initial stage of studying computer science, the concept of a model is present in problem solving. Later on, modeling is distinguished as a separate method of solving problems, and thus modeling can be used in secondary education. Today, school textbooks cover the Pascal (Object Pascal) programming language for the Lazarus and Python development environments, which can be used to perform computer modeling. Programming languages are fundamentally different, and accordingly, their application will be radically different. Pascal uses a compiler, so we can create application software and only then use it for research. To save data, you need to use files, and there is an acceptable code execution speed.

An interpreter is used for the Python programming language, so in the course of the modern experiment, we can change the preliminary research plan depending on the results obtained or our own vision of further steps. For long-term data storage, it is necessary to use files, there is a possibility to use modern data structures and methods of their processing, and slow execution of instructions. An equally important point when using Python is the use of a sufficient number of extension libraries. We use Pandas, NumPy, SciPy, Matplotlib, Seaborn, and other libraries. With these libraries, an interactive session in the Python environment turns into the same full-fledged data processing environment as MATLAB, Octave, R-Lab, and SciLab.

Speaking of our topic “Coulomb’s Law,” we can use Object Pascal to create an application that calculates the value of the interaction force for the entered values of charges and distances (figure 5). In addition, we can plot the dependence of the interaction force on the distance between charges.

If we look at our topic “Coulomb’s Law”, we can create an application in Object Pascal that will calculate the value of the interaction force for the entered values of the charges and distances (figure 5). In addition, we can plot the dependence of the interaction force on the distance between the charges.

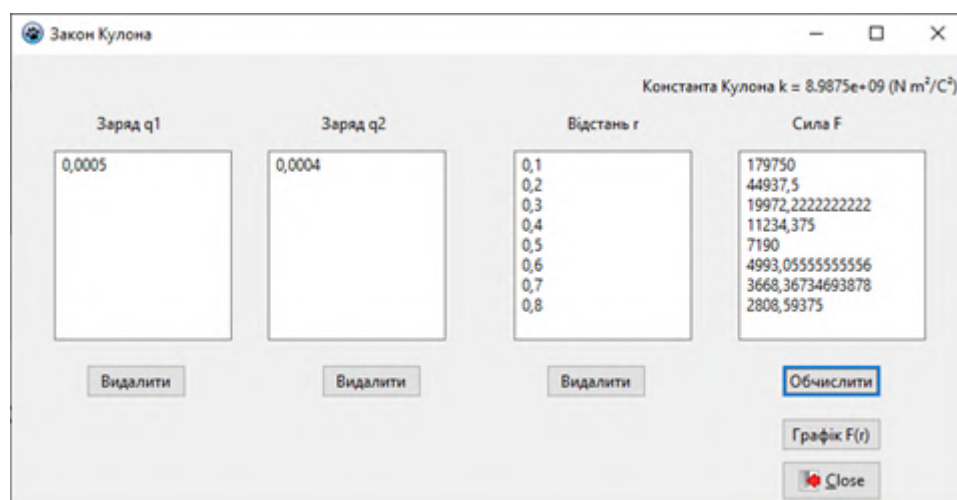


Figure 5. Calculation of the value of the Coulomb force by an application running in the Lazarus development environment.

To visualize the interaction of point electrostatic charges, power lines are usually drawn to show how the charges interact with each other. For such a visualization, one can also use the Python programming language using appropriate libraries or ready-made developments (figure 6, figure 7).

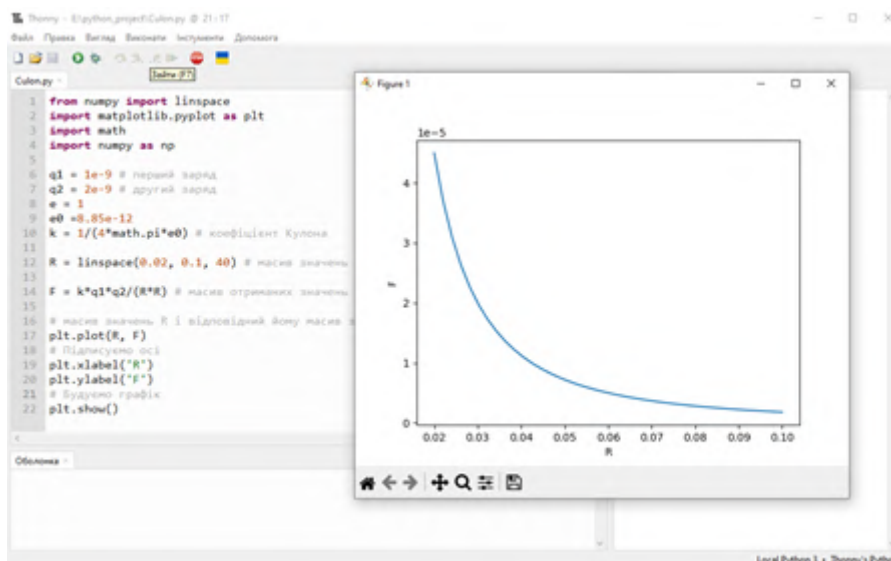


Figure 6. Calculation of the value of the Coulomb force by an application made in the Lazarus development environment.

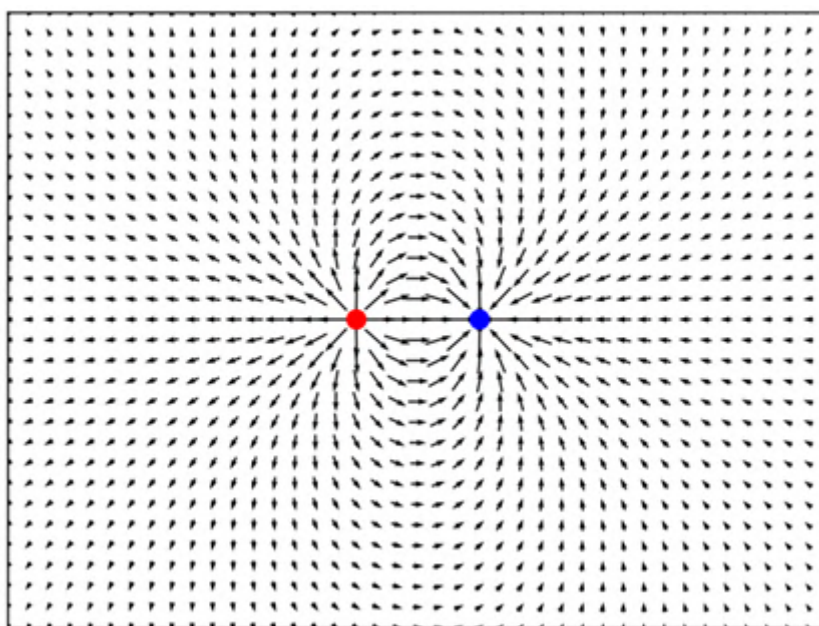


Figure 7. Vector graph of the electric field from the electrostatics 0.2.0 package [22].

It is advisable to combine the analysis of the impact of the use of computer modeling tools on the results of educational activities with the analysis of the results themselves, which depend on the purpose of the educational process. These results depend mainly on the level of education and profile. To a certain extent, the results of studying physics at the level of general education, vocational, professional pre-university and higher education are united by the fact that as a result, a single physical picture of the world should be created, which is a prerequisite for the formation of a scientific worldview. In addition, the structure of ideas about processes in the world around us is formed, which allows us to form technical thinking, which in turn helps us to

adapt to the current pace of development of science and technology. However, depending on the chosen profile of study, the depth of such a technical outlook will vary. It is logical to conclude that the amount and depth of knowledge gained depends on the chosen future specialization, and this allows us to assert that the range of knowledge should range from the level of possession of information about how the world around us works to a complete understanding of all laws and processes with the ability to independently analyze and synthesize information and apply the acquired knowledge. Thus, the use of computer modeling tools should also correspond to these limit cases.

The easiest way to use computer simulation is to visualize the learning material. This approach is effective because most of the information a person receives is through the perception of an image. And in the case when it is only necessary to create an idea of a certain process, it is enough for students to see and understand the cause-and-effect relationships that correspond to this process. This type of activity is better suited for the initial stages of learning physics or when physics is not a core subject (school, vocational education, colleges). That is, at a simpler level of use, it makes sense to emphasize the use of ready-made simulations. In the case when a student has to master the educational material in more depth, along with developing the skills of practical application of the acquired knowledge, it is necessary to move on to the creation of appropriate mathematical models, which in itself is the first step towards creating the necessary computer models by the student. This approach is better suited for college and university students.

If we take into account this differentiation of the approach to the use of computer modeling, then in general we get a gradual increase in the complexity of the learning material itself, from simple observation to the development and implementation of certain products (simulations, computer programs for calculating process parameters, applications, etc.). This approach has a positive impact on the quality of education, and, in addition, it allows for the creation of a certain basis for the development of creative abilities, which are realized through mastering the processes necessary for scientific research. In fact, by using computer modeling as a means of obtaining the student's own results, we encourage them to develop their own learning system, which can later become the basis for their own system of scientific research.

6. Discussion of results

We used the expert method to evaluate the considered modeling tools for studying the interaction between charged particles. We had two groups of experts (Donetsk, Khmelnytskyi, and Odesa regions), the first group consisted of professors and teachers of physics, and the second group consisted of students and pupils. The questionnaire consisted of the following questions for both the first group and the second group from the following list:

1. Is it reasonable to use electronic educational resources in the process of teaching physics?
2. Does the modeling method help to activate cognitive activity?
3. Will you use the computer modeling method in the future?
4. Did you get any ideas about the use of computer modeling in the further study of physics?
5. Rank the applications in descending order of attractiveness to you:
 - (a) off-the-shelf simulators
 - (b) spreadsheets
 - (c) computer math packages
 - (d) own developments in programming languages

A total of 12 physics teachers and professors and 72 students took part in the survey. The results of the survey are shown in figure 8. The majority of teachers and lecturers agree that e-learning resources are a useful teaching tool. Teachers expect computer modeling to

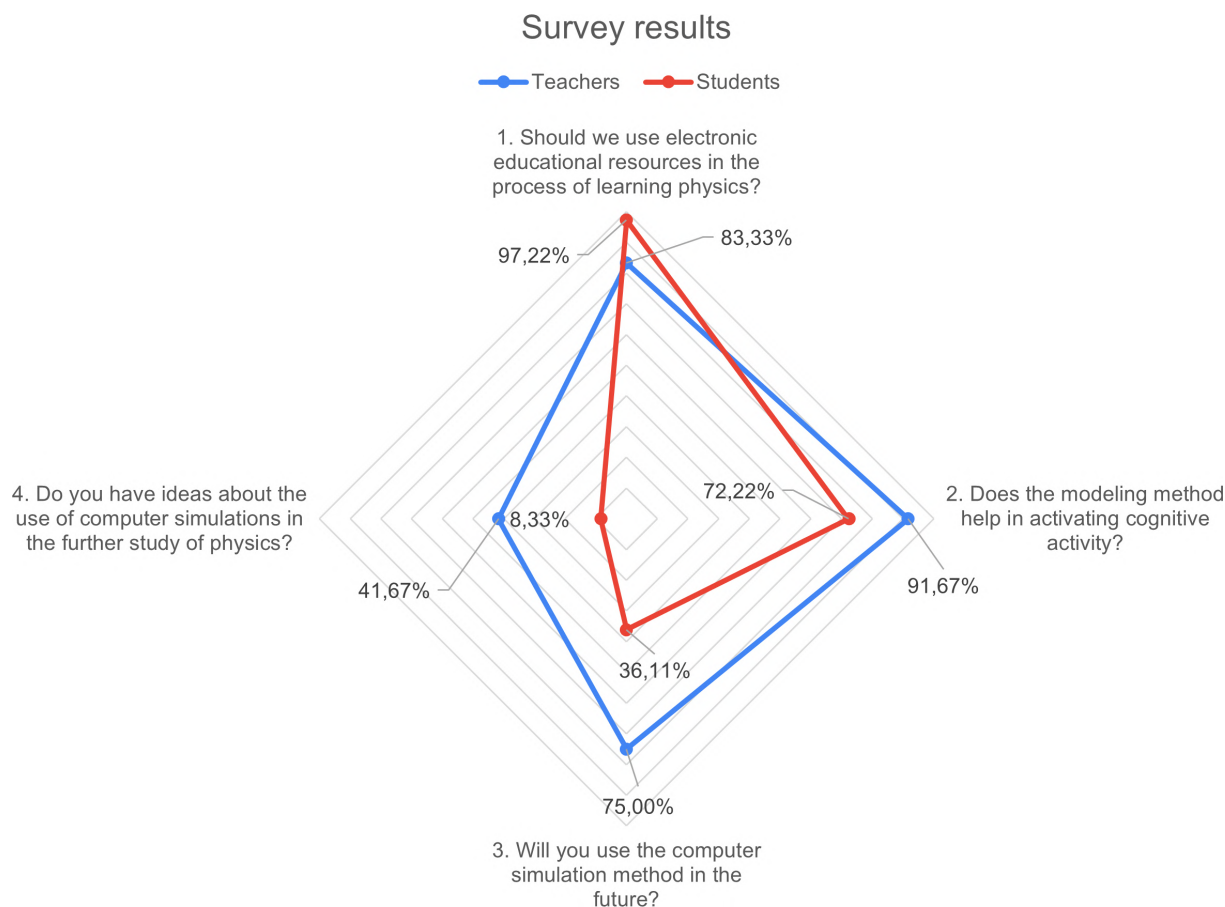


Figure 8. Survey results.

be interesting for students. Teachers agree that it is a useful method of both problem solving and cognition, but they are not willing to take the initiative to promote it themselves. For students, new things in physics class are always interesting, and therefore they are happy to use electronic educational resources. The majority of students agree that e-learning resources are useful for understanding the material. Only a third of students perceived the computer modeling method as interesting and useful for learning. And only 6 students out of 72 are ready to continue self-educational research activities using the computer modeling method.

The rating is almost identical in the opinion of both teachers and students (figure 9). The highest rating was given to off-the-shelf simulators because they are “bright” and “ready to use”. The lowest rating was given to their own developments in programming languages, because “it’s programming, so it is difficult”.

7. Conclusions

Based on the analysis of scientific publications, it can be concluded that computer modeling is an effective tool for solving a wide range of problems in education and research. In particular, it allows conducting virtual experiments, visualizing complex processes, building predictive models, etc.

A comparative analysis of modeling tools has shown that mathematical packages are the most functional and convenient for use in the educational process. At the same time, off-the-shelf simulations also provide opportunities for modeling, although they are not as versatile.

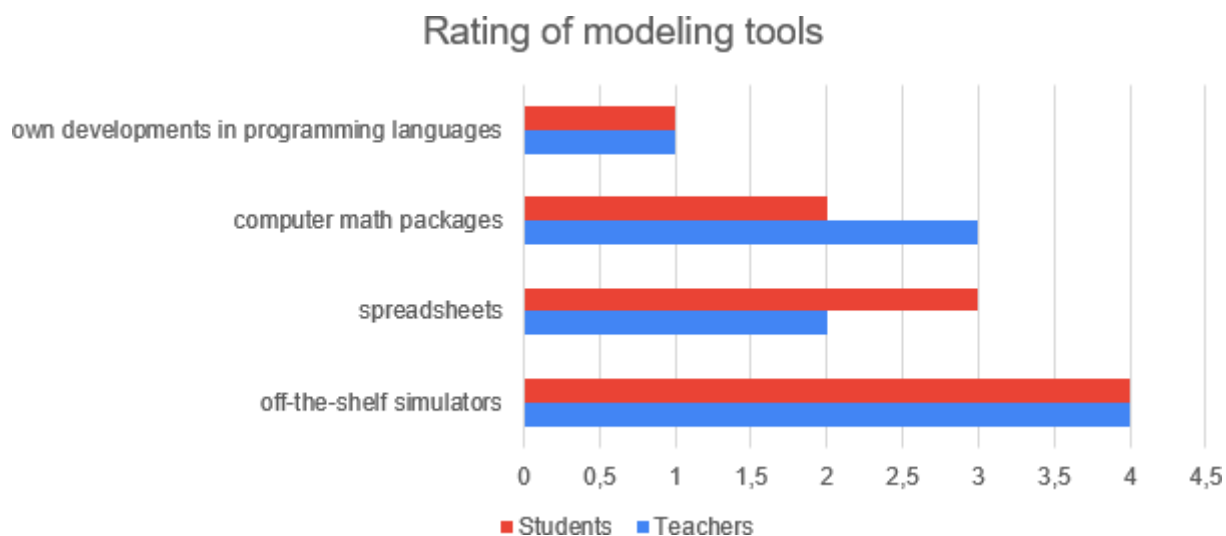


Figure 9. Rating of modeling tools.

General-purpose application software, in this case spreadsheets, is suitable for using modeling as a method of solving problems and improving research competence. Attention should also be paid to the use of programming languages in computer modeling, despite the fact that it is necessary to have appropriate programming competence.

Therefore, the use of computer modeling tools in education and research is appropriate and effective. At the same time, attention should be paid to the selection of optimal modeling tools and means for specific tasks.

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Professionally oriented tasks for learning and using mapping technology with ArcGIS tools

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Abstract. The article substantiates the expediency of using professionally oriented tasks for learning the technology of the mapping process using ArcGIS, taking into account the peculiarities of the training specialists of natural sciences. Socio-economic mapping by means of ArcGIS is an important step for creating management systems to support decision-making by future geographers and others. The main aspects of the introduction of professionally oriented tasks into the educational process of pedagogical institutions of higher education have been clarified. Educational and methodological guidelines for studying and using the technology of mapping with ArcGIS tools have been developed for students and future geographers who expect to perform professionally oriented tasks in the development of maps. For the practical preparation and development of a series of maps that provide visual information for an objective analysis of Ukraine's indicators, we used information from the State Statistics Service of Ukraine, the Main Statistical Offices of Ukrainian regions. A series of maps, created by different methods and connected by one topic, was prepared and developed, among them the creation of a cartogram of the population of the regions of Ukraine using the method of quantitative background. An experimental verification of the effectiveness of the use of professionally oriented tasks for the study and use of mapping technology by means of ArcGIS by future teachers-geographers proved an increase in the level of development according to the specified criteria: motivational, cognitive and personal-reflective with the corresponding indicators. The mapping approaches presented in this paper based on the implementation of professionally oriented tasks allow students to apply the acquired knowledge and skills and give them the opportunity to flexibly adapt to situations arising in the future professional activity of a geographer.

1. Topicality

Nowadays, the use of digital technologies has become ubiquitous [1]. The culture of communication with the computer becomes part of the general human culture. Universities have always played an exclusive role in the education system, and special attention was paid to the quality of professional, pedagogical and scientific training of students. At this stage of society's development, there is an acute question of creating a fundamentally new system of education and upbringing, which will be based on new approaches and trends in the world of informatization. However, it should be noted that the mechanisms of effective use of information technologies to activate the educational and cognitive activity of future teachers when studying professional disciplines in a pedagogical university have not been sufficiently researched, which causes problems in their implementation in practice [2, p. 16].



One of the main tasks of education in pedagogical institutions of higher education is to teach a student to learn, to give him a basis for further self-improvement, to teach him to independently acquire the knowledge needed for his profession [3]. After all, the skills of most teachers to use highly specialized digital software environments in the lessons of physics, mathematics, chemistry, geography, etc. are insufficient. The success of solving this problem largely depends on qualitatively new approaches in the process of informatization of education and on the development and implementation of new schemes for the organization of the educational process. Already in the process of studying at a higher education institution, a student must acquire skills in the use of digital technologies in his/her educational, research and future professional activities.

Informatization of education is a necessary component of the training of specialists in any field of knowledge and is expedient not only as a method of quickly and effectively mastering one or another discipline being studied, but also as a way of life in a modern world saturated with information technologies [4, 5].

Legal relations that arise during the formation and implementation of the National Informatization Program are regulated by the Law "On the National Informatization Program". The following terms have been defined: "information and communication technologies is the result of intellectual activity, a set of systematized scientific knowledge, technical, organizational and other decisions on the list and the sequence of operations for the collection, processing, accumulation and use of information products, provision of information services" [6].

There is an urgent issue of training future teachers who are ready to work in new conditions, implement personal-oriented learning, develop new teaching technologies, implement differentiation and variability of teaching, and implement the latest methods [7, p. 63].

Different approaches to the professional training of students in higher pedagogical educational institutions have been developed in the following scientific works: Gudyreva – introduction of information and communication technologies in the educational process of a higher educational institution. Informatization of the educational process in higher education institutions contributes to the accelerated process of adaptation of the student as a future specialist to his/her professional activity, improves the quality of his/her training, provides an opportunity for the student and specialist to navigate more freely in modern life in general and in the field of professional activity, in particular, [8, p. 105]; Olefirenko – teaching students the method of projects with the use of information and communication technologies, which involves increased requirements for the teacher's professional training, his/her pedagogical competence, erudition, and general culture [7]; Tsidylo et al. – a computer simulation of population reproduction rate on the basis of their mathematical models [9]; methods of future natural sciences teachers training to use smart technologies on the basis of learning apps – Stepanyuk et al. [10]; the use of professionally oriented tasks in the study of information technologies in pedagogical higher educational institutions has been considered by Velgach and Grod [2, p. 14-24].

The system of professionally oriented tasks needs implementation and constant development. Their structure should correspond to the developed structure of professional skills. This approach provides an opportunity to motivate students, improve indicators of educational activity, and intensify the process of training future specialists due to the professional orientation of tasks and the gradual formation of skills. According to Vlasenko, a professionally oriented task is a task whose conditions and requirements define a model of a certain situation that arises in the teacher's professional activity [11, p. 57].

The set of means, methods and techniques for collecting, storing, processing, analyzing and displaying spatial information is unified under the name "Geographical information technologies". Geoinformation systems form a new technology within which aspects of the interaction between man and the environment are investigated [12, p. 128].

It is worth noting the study by Kozachenko et al. [13], in which the methodological

foundations of cartographic modelling are considered, its object, subject and means are substantiated, the main directions of cartographic modelling of the society-nature system are defined, as well as the place and role of geoinformation mapping in the system of cartographic disciplines, the essence, specifics and types of geoinformation, methods of creation and experience of using cartographic data banks, methods of mapping in interactive mode are outlined.

Spatial data provide the formation of “digital” or “electronic” maps. According to Rudenko and Chabanyuk, they can be reproduced in raster or vector format [14, p. 55].

The purpose of the article is to demonstrate the development of professionally oriented tasks for the study and use of future geographers by mapping technology using ArcGIS services.

In accordance with the purpose of the study, the following tasks are set:

- (i) to find out the concept of professionally oriented tasks and requirements for their implementation in the educational process in pedagogical institutions of higher education;
- (ii) to develop professionally oriented tasks from the course “Digital technologies in education and science” for geography students (to study the theoretical and practical aspects of GIS application, to analyze the possibilities of modern GIS as a teaching tool, to develop training instructions for working in ArcMap).

2. Research methods

A complex of interrelated methods was used to solve the tasks set in the research:

- 1) theoretical: analysis and generalization of scientific and pedagogical literature, modelling of the educational process;
- 2) empirical: observation of the educational process in a higher education institution during the “Digital technologies in education and science” training course, test tasks, questionnaires, questionnaire of personal evaluations;
- 3) GIS software: ArcMap is the main ArcGIS application, which is used to create maps and solve various GIS tasks, both general and highly specialized. It is based on an electronic map and works with a map document (*.mxd);
- 4) a pedagogical experiment on the study of the effectiveness of the use of professionally oriented tasks for the study and use of mapping technology by means of ArcGIS by future teachers-geographers.

3. Research results

Each professionally oriented task should include a complete cycle of solving it. We implement compliance with all stages of this cycle when performing the developed tasks.

The implementation of the developed tasks was carried out in the software environment, which was chosen according to the criteria defined by us for the compatibility of the software environment with the specified problem:

- 1) the maximum possible correspondence of the functionality of the software environment to the full cycle of solving professionally oriented tasks;
- 2) the possibility of a software environment for providing services of a complex nature, i.e. for mapping, editing, analyzing and managing data;
- 3) intuitive interface and 1-window interface technology;
- 4) the maximum possible correspondence of the functionality of the software environment to the requirements for displaying specific geographic information, a certain type of objects, for example, rivers, lakes, roads, administrative boundaries or animal habitats.

Among the existing wide range of software environments for creating a series of maps, we analyzed the online services of powerful Web cartographic or GIS portals (ArcGIS Online, Google Earth, Google Maps, Wikimapia, Bing Maps, MapQuest, Yahoo! Maps, MultiMap.com, Map24.com, Expedia.com, MapsOnUS, eAtlas, etc.) [15]. ESRI desktop products of the ArcGIS family (ArcView, ArcEditor, ArcInfo), basic programs ArcMap (solutions to cartographic problems), ArcCatalog (access and management of spatial data in a local network or via the Internet) and ArcToolbox (geoprocessing of spatial data) are united by a common architecture and interface, but they differ in functionality, number of geoprocessing and spatial analysis tools [16, 17].

After analyzing GIS environments, we have concluded that ArcMap is the primary application for mapping, editing, analyzing, and managing data. In ArcMap, you can make maps from layers of spatial data, choose colours and symbols, query attributes, analyze spatial relationships, design map placement, and more.

The ArcMap interface is based on the one-window technology, which involves opening each project in a separate window. The interface's appearance includes the following main elements: table of contents (or TOC), menu panel, toolbars, and status bar.

The program interface may change depending on the version and configuration of the software. The data displaying the cursor coordinates depends on the selected coordinate system and basic project settings (Data Frame properties-General).

The ArcMap application window consists of a map window for viewing spatial data, a table of contents for listing the layers displayed in the map window, and various toolbars for working with the data. ArcMap is launched through the .exe file of the ArcCatalog-Folder Connections window or through the path Main menu ArcMap.

Each ArcMap session can display only one project. A user can work on multiple projects simultaneously by starting additional ArcMap sessions. If the system registry has not been changed and no additional utilities have been run, the startup window should appear. In the ArcMap environment, it is customary to use the term "project" instead of the term "document", which is related to the nature of these documents, namely individual cartographic and geoinformation projects. The format component of these terms includes two file extensions *.MXD (project) and *.MXT (template).

In ArcMap, geographic information is displayed on maps as layers, each representing a specific type of feature, such as rivers, lakes, roads, administrative boundaries, or animal habitats. The layer does not store real geographic data but data stored in coverage files, shapefiles, geodatabases, images, and grids. In this way, data linking allows map layers to automatically map the most up-to-date information to the GIS database.

The table of contents is a list of all the layers of the map and shows what features each layer represents. A tick box next to each layer indicates whether the layer is enabled, i.e. whether it is visible/hidden in your project. The order of layers in the table of contents determines the order and priority of their display: the layers that are located in the table of contents above are displayed on top of those located below, for example, the layers that make up the background of your map should be at the end of the table of contents.

The layers in a table of contents can be grouped into data frames. A data frame is a group of layers that are displayed together as a self-contained structure. Each time a map is created, a data frame is present on it. It appears at the top of the table of contents under the name "Layers", but the name can be changed. For most maps that the user works with, there is no need to use data frames: the user can simply add layers to the project, depending on how they will be displayed in the table of contents. If a map contains more than one data frame, one of them is always active. Viewing an ArcMap page with an additional data frame is possible via the Table Of Contents tab, where the active frame is highlighted in bold.

To work with a map, the user opens it in ArcMap. If you don't know exactly where it is

located, you can find it through ArcCatalog by browsing your database folders and opening it in ArcMap. If the ArcMap application is running, the map can be opened directly from it.

The map does not store the spatial data it displays. It simply points to the location of data sources on disk: geodatabases, coverage files, shapefiles, or rasters. This way, when you open a map, ArcMap always checks the data connection. If the application cannot find the data, for example, if the data source was accidentally deleted, renamed, moved, etc. by the user, ArcMap prompts the user to find it. If the data is not available, the user can still include it in the map, however, the layer will be part of the project, but will not be displayed.

Adding spatial data in the ArcMap environment is done using the “Add Data” command in several ways. In any case, a dialogue box for selecting spatial data and sources appears.

Map layouts are created according to the following algorithm. Switch to map layout and layout display mode. We select the size and orientation of the layout using the “File” menu and the “Page and Print Setup” command, where we specify the necessary layout parameters:

- selection of the printer for printing the map (Properties...);
- setting the paper size (Size);
- orientation of the project page (Portrait or Landscape);
- scaling map elements proportionally to changes in page size;
- shows printer margins on the layout.

It is advisable to set the orientation of the page before starting the development of the map. If autoscaling is disabled, the map elements will change according to the new orientation. It is useful to be able to see in Layout View the display of the printer fields so that you do not place map elements outside the print area. If we work with a virtual page, the size of which does not correspond to the size of the page, we can use the printer fields.

ArcMap has two map views: Data View and Layout View. When the user wants to view geographic data on the map, he selects Data type. Data view is a common view for exploring, displaying, and querying map data. This mode does not show map elements such as headings, north arrows, and scale lines, but allows the user to focus on a frame of data for further editing or analysis.

When preparing a map for a wall format, illustration in a report, etc., it is worth working in layout mode. The layout view is the external view of the map, where the user sees the virtual page on which the map is placed. Here, you can perform the same operations as in the Edit View mode, but in addition, you can develop the design of the map.

One of the main characteristics of spatial data is the coordinate system, and its definition for an information project is one of the key tasks. The quality of data, their collection, analysis and display depends on it. Selecting and changing the coordinate system for the project being created is carried out in several ways, one of them is to select the Data Frame Properties command from the pop-up menu by clicking the right mouse button on the cursor within the data frame. After invoking this command, the Data Frame Properties dialogue box appears, which provides access to many frame and map layout properties through one of the following appropriate tabs: Feature Cache, Annotation Groups, Extent Indicators, Frame, Size and Position, General, Data Frame, Coordinate System, Illumination, Grids. For example, the dialogue box for selecting and changing coordinate systems of a geoinformation project is opened through the Coordinate System tab.

In the “Coordinate system” tab, the following options are available: in the upper left part, the “Current coordinate system” option, which displays information on the existing coordinate system, in the lower left part, there is “Select coordinate system”, which allows you to select the necessary coordinate system. In the right part of the tab there are commands that allow you to modify, create and import properties of coordinate systems; add and remove them from the

Favorites list. Sometimes you need to place several map elements along one line. By clicking on the element/elements of the map, we select them while pressing Shift, press the right key on one of the selected elements, select the command “Align” and one of the required items. Then drag the selected elements with the mouse to the desired place on the map.

Map elements are converted into graphic objects using the “Convert to Graphics” command (from the group of graphic elements). Having ungrouped a group of graphic elements (Ungroup), we can change them separately. After completing the editing process, grouping (Group) should be performed for ease of movement on the map (figure 1).

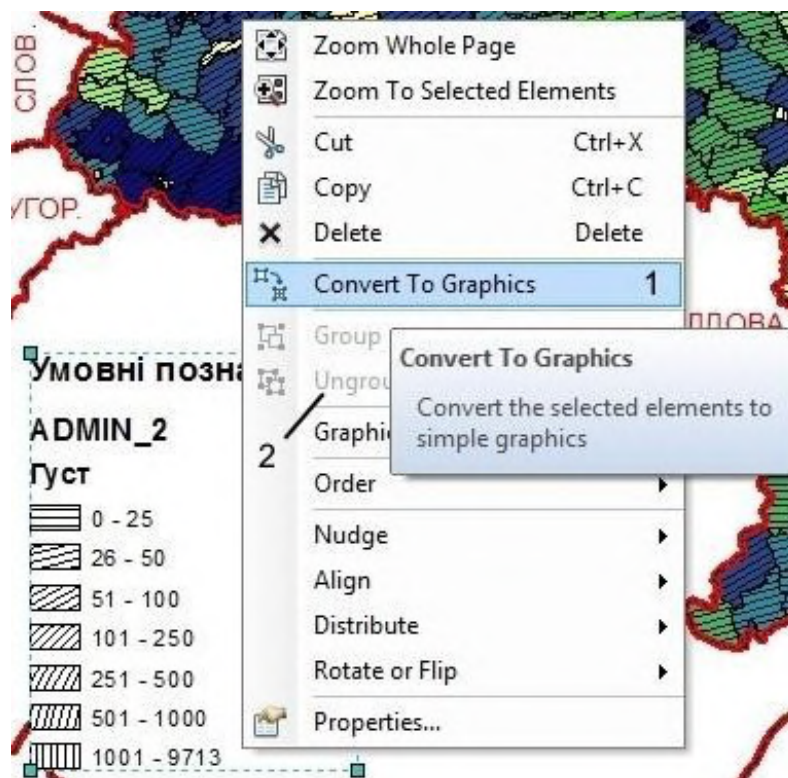


Figure 1. Converting map elements into graphic objects.

After the user has created a map, it must be exported from the map document to a different file format (File Export Map... Save to (specify directories, subdirectories) specify file type specify file name Options (Format) click the save button). You can export maps to several types of image files: .emf, .eps, .ai, .pdf, .svg, .bmp, .jpg, .png, .tif, .gif. Each format fulfils its purpose: AI saves most of the layers; PDF is created taking into account the possibility of working on different platforms; SVG is for XML files specially designed for viewing web pages; JPEG is for compressed image files; PNG is a special compression format for the Internet, etc.

Accordingly, we faced the question of developing tasks aimed at the formation of the professional and technological abilities and skills of future teacher-geographers, completing which students should independently come to the opinion that a teacher’s professional activity is not reduced to separate fragmentary knowledge, methods, or educational disciplines. This will be facilitated by the fact that students will transfer certain algorithms and skills from one discipline to another, reflecting on the degree of their development and setting themselves self-educational tasks.

We took the data for creating the map from the State Statistics Service of Ukraine [18] and entered it into the attribute table (“POPULATION” column) (table 1). Excluding the

temporarily occupied territory of the Autonomous Republic of Crimea and the city of Sevastopol.

Table 1. Population (estimated) as of October 1, 2020.

Regions of Ukraine	Number of population	Regions of Ukraine	Number of population
Vinnitsia	1,534,744	Luhansk	2,232,887
Volyn	1,029,533	Lviv	2,536,053
Dnipropetrovsk	3,285,626	Ternopil	1,033,566
Donetsk	4,332,016	Kharkiv	2,735,862
Zhytomyr	1,200,338	Kherson	1,070,567
Zakarpattia	1,251,697	Khmelnitsk	1,304,602
Zaporizhia	1,673,914	Cherkasy	1,256,770
Ivano-Frankivsk	1,381,505	Chernivtsi	908,409
Kyiv	1,725,893	Chernihiv	1,062,810
Kirovohrad	984,864	City of Kyiv	2,962,881

Let us consider creating a map of the population of the regions of Ukraine in ArcMap using the quantitative background method. This method is often used to construct population maps, economic maps, and some political-geographical maps. To demonstrate this method, a vector map of Ukraine was used, adding the “POPULATION” column to the attribute table.

Open the Symbology tab, go to the Quantities tab and adjust the required parameters. By choosing the Graduated Colors function, we set the number of classes into which the map legend will be divided. Next, choose a colour scheme for the created map. The next step is the classification of parameters for dividing indicators into classes and choosing a classification method. We chose the Defined Interval method. The final stage of creating a map is setting signatures of regions of Ukraine. By right-clicking on the Ukraine Regions layer, select Properties, and set the necessary text display parameters on the Labels tab. We adjust the labels of areas on the map in the Layer Properties window (Labels tab). To display region labels on the map, select the Label Features option on the Ukraine-Regions layer (figure 2).

After creating the layout elements, the map is ready for printing.

Experimental verification of the effectiveness of the use of professionally oriented tasks for the study and use of mapping technology by means of ArcGIS by future geographer teachers.

The developed professionally oriented tasks were offered to students of the Faculty of Geography when studying the course “Digital technologies in education and science” during two academic years (2021, 2022 and 2023 1st semester) in the preparation of specialists of the educational level of the Master of Ternopil Volodymyr Hnatiuk National Pedagogical University according to the educational programs “Secondary education (Geography)” in the speciality 014.07 Secondary education (Geography), educational program “Ecology” in the speciality 101 Ecology, educational program “Geography” in the speciality 106 Geography, educational program “Earth sciences” in the speciality 103 Earth sciences, educational program “Tourism” in the speciality 242 Tourism. A total of 173 students were involved in the experimental work (table 2).

Students were given the task of creating a cartogram in laboratory-practical classes, the sequence of which is described above. The use of such tasks in the process of training a future specialist provides an opportunity to focus attention on learning: basic modern and promising data processing systems; the possibilities of using digital technologies in the process of preparing and conducting geography classes; principles of processing tabular information collected in the process of practical activity of the future geographer; possibilities of visualization of the results of measurement procedures; analysis and forecasting of processes based on statistical data;

questionnaire of personal evaluations.

At the beginning of the research, it was established that according to all the defined criteria, the students have a low level of ability to study and use mapping technology (53%). There is a significant (33%) indicator of the average level and a small number of students (14%) who have a high level of ability to study and use mapping technology, and therefore the investigated problem is timely for solution.

The effectiveness of the introduction of professionally oriented tasks into the educational process is confirmed by the positive changes that were detected after the completion of the formative phase of the experiment (table 3).

Table 3. Indicators of students' ability to learn and use mapping technology.

Level	Motivational				Cognitive				Personal-reflective			
	Before the experiment		After the experiment		Before the experiment		After the experiment		Before the experiment		After the experiment	
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
High	28	16,1	69	39,9	24	13,9	65	37,6	24	13,9	65	37,6
Average	56	32,4	77	44,5	57	32,9	78	45,1	59	34	80	46,2
Low	89	51,4	27	15,6	92	53,2	30	17,2	90	52	28	16,2

As evidenced by the data of the experiment, the high level of student's ability to study and use mapping technology in the groups has increased by 24% since the beginning of the study, the average level has increased by 12%, and the low level has decreased by 36% after the completion of the formative phase of the experiment. According to statistical calculations, changes in the level of student's ability to study and use mapping technology due to the implementation of the methodology of using professionally oriented tasks are statistically significant, that is, probable.

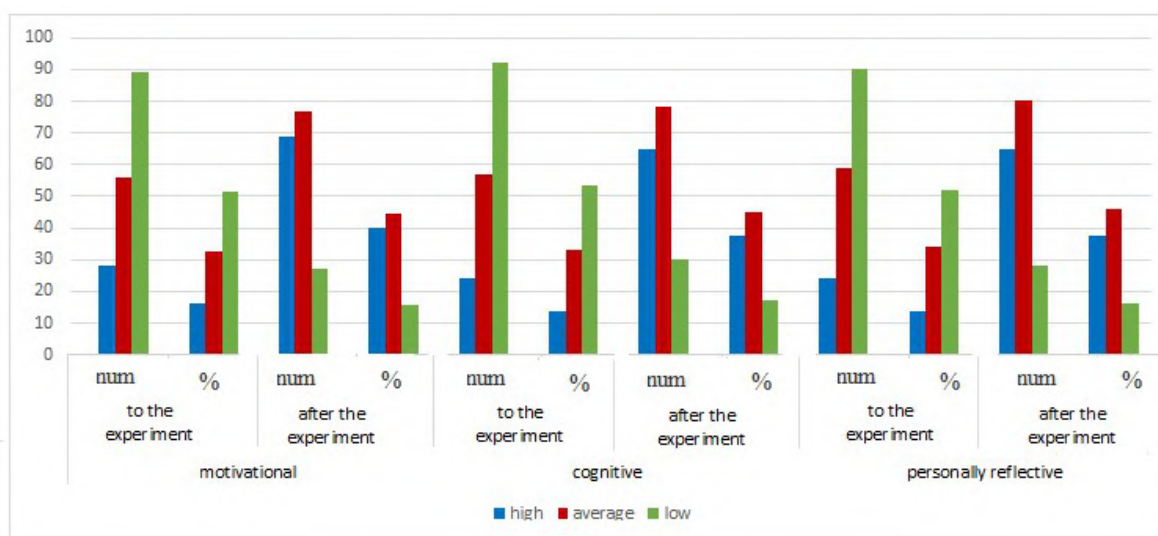


Figure 3. Indicators of motivational, cognitive and personal-reflective criteria.

The obtained results confirm the effectiveness of the implementation of the methodology and its impact on increasing the level of student's ability to study and use the mapping technology of future specialists.

4. Discussion of research results

A specific feature of professionally-oriented technologies is the professional-activity focus of training on students' mastery of professional activities in the educational process, which is ensured by the following factors: orientation of the educational material to solving the tasks of professional training of the future teacher; the complex nature of the specialization, which covers all connections of the course with relevant disciplines, course and master's design and other types of research activities of students; preferred solution in practical classes of applied tasks, which are necessary for the student to master the chosen profession; focus on the development of the creative personality of the future teacher, who is capable of independent professional activity; development of professional value orientations, formation of a professional position, development of the need and readiness for professional and personal self-improvement [19].

The practical value of ArcGIS for the development of cartographic materials in educational institutions is not limited to one stage of creating maps but is actually a tool for the full cycle of creating and preparing maps for their publication. With a wide range of tools, methods and ways to display information about the terrain, ArcGIS offers a wide range of options for presenting certain data on the map, which perfectly emphasizes the statement that the map is a model of the terrain and its representation.

5. Conclusions

The significance of the practical application of web cartography for highlighting the peculiarities of the use of web technologies in mapping is characterized by a low level of geoinformation support and, therefore, requires appropriate cartographic resources, which will include information and operational tools intended mainly for scientific, educational, geo-monitoring, tourist-recreational and local history-cognitive purposes. This is ensured by the existing toolkit of visualization, search and formation of geospatial queries and analysis.

Completion of professionally oriented tasks encourages students to analyze, comprehend and systematize information, promotes better motivation to study, and, most importantly, increases their level of professionalism. Quantitative and qualitative analysis of the results of research and experimental work confirms the effectiveness and expediency of the approbation of the methodology of using professionally oriented tasks with the use of mapping technology by means of ArcGIS. Prospects for further scientific research are possible in the direction of analyzing the results of the implementation of specially organized professionally-oriented training, substantiating the interdisciplinary connections of professional training subjects, as well as developing professionally-oriented tasks.

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Ontological analysis of business process modeling of higher education institutions based on the electronic document management system

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Abstract. Improving the quality of the educational process, bringing it to modern requirements is a complex task, the solution of which requires a systematic approach from higher education institutions and the development of a strategy to improve the quality of service and efficiency of the institution. Formalization and modeling of the management business process allows for effective management decisions. When analyzing large amounts of information to effectively solve the problem of data structuring, as well as the problem of forming new knowledge, it is proposed to use an ontological approach based on the use of associative rules. The ontological analysis of modeling business processes of higher education institutions and analysis of the structure, functions and information flows of organization and management of educational activities based on the structural approach is carried out. Improving the quality of the educational process, bringing it to modern requirements is a complex task, the solution of which requires a systematic approach from higher education institutions and the development of a strategy to improve the quality of service and efficiency of the institution. The use of an ontological model of interaction between subjects and objects of the system makes it possible to assess the level of system efficiency and build a simulation model of management, which will allow predicting the emergence of critical business processes that may lead to a decrease in the efficiency of decision-making and disruptions in the functioning of higher education institutions and their departments.

1. Introduction

1.1. Relevance

The functioning of an organization or enterprise requires process automation, which combines a set of administrative and educational processes. In educational institutions, it is important to organize the management of departments to provide services for educational, scientific and research activities. Higher education in Ukraine, as well as other areas of industrial and non-industrial activity, is increasingly under pressure from the market. Acquiring new responsibilities and freedoms, management processes are becoming more and more adequate in line with those used in the business sector. In nowadays, when the educational process is considered as a business process, higher education institutions (HEIs) have faced a number of problems related to effective management processes. This is primarily due to the lack of funding in general and budget funding in particular, as well as the timely and sustainable exchange of information, which is associated with large volumes of poorly structured or unstructured documentation [1]. It



is important to study the features of information modeling, timeliness, in creating an ontological approach to the distributed information environment, as well as an ontological approach to the application of similar models in different subject areas [2–4]. The challenges that cause the transformation of the essence of higher education in Ukraine contribute to the orientation of university education to take into account and meet the educational needs and demands of young people as direct users of higher education institutions. At the same time, during the period of reorientation of society from the industrial paradigm of existence to the information one, the level of intellectual potential of the nation in general and the level of intellectual development of each individual in particular becomes a decisive factor in the country's development. Given the above, the educational process in a higher education institution should be adaptive and proactive, which leads to a rapid and adequate response of the content of the educational process to new challenges, to the needs and demands of consumers of educational services provided by the higher education institution. The basis for achieving these requirements is the implementation of an electronic document management system. The research is based on publicly available descriptions of real business processes in existing universities in Kyiv, Rivne, and other institutions, presented in various literature and our own materials from Kyiv National University of Construction and Architecture (KNUCA). However, the aim was not to create a comprehensive overview material, as the existence or availability of such processes is sufficient for further research.

1.2. Description of the problem

One of the most acute problems of the creative economy is the rapid obsolescence of employees' professional knowledge and, as a result, the mismatch between the structure of demand and the structure of supply in the labor market. The university education system is the main area of training highly qualified personnel capable of creatively perceiving rapid changes in the business environment.

However, it does not diversify the range of specialties, the structure of training courses, the content of programs and teaching methods quickly enough. The main reasons for this include: the traditional use of formal parameters of higher education before the actual quality of knowledge acquired; excessive regulation of higher education institutions by higher government agencies; poor interaction between HELs and enterprises in the real sector of the economy – the main “buyers” in the labor market, which are able to objectively assess the professional level of university graduates. This market should be equally oriented toward direct consumers of higher education services – students – and labor buyers – enterprises and institutions. The structure of higher education services may include recruitment services aimed at selecting and training or systematic retraining of specialists for enterprises and organizations.

The problem of ensuring the development of higher education institutions has always been relevant, especially in the context of a massive shortage of students in specialized specialties and limited financial resources. The labor market requires specialists with a high level of professional training, capable of solving complex problems and being mobile. Improving the quality of the educational process and bringing it in line with the requirements of employers is a complex task that requires a systematic approach to pedagogical management. To solve this problem, the technology for managing educational business processes, which is flexible and able to withstand economic threats, deserves attention.

The peculiarities of managing educational business processes are relevant in the context of unprofitable activities of private higher education institutions, which requires additional scientific research in this area, based on principles:

- W. E. Deming's quality principles. “Continuous Process Improvement” (CPI – Continuous Process Improvement [5]), should be considered exclusively as a system (TQM – Total Quality Management [6]).

- The Kaizen concept of Masaaki Imai is focused on the consumer, whose interaction with the company becomes the driving force for improvements, gradual improvement of quality and business processes [7].
- Business Process Reengineering (BPR) by M. Hammer and J. Champy is aimed at achieving dramatic or leapfrog improvements in critical, modern performance indicators such as cost, quality, service, and pace [8]. One of the problems that are solved within BPR is the description of existing business processes and the construction of a management model for the HEI.

The practice of using reengineering has shown that this method is necessary, especially in the context of global economic reform and active implementation in the world economic system. BPR is a direction that has emerged at the intersection of two different areas of activity – management and informatization. That is why reengineering requires new specific means of presenting and processing problematic information that is understandable to both managers and information system developers. In the current environment characterized by a high degree of uncertainty, one of the most promising approaches to forecasting is scenario analysis [9]. The fundamental difference between this method and others is that it does not use retrospective extrapolation when developing scenarios for the development of the situation. Scenario forecasting allows to obtain a detailed description of the sequence of events that with a given probability can lead to the desired or planned state of the higher education institution under different development options. Therefore, the use of the scenario approach is also appropriate for strategic planning in higher education institutions. The use of scenario forecasting based on an ontological approach will allow, on the one hand, to identify, evaluate and reduce the level of uncertainty of key factors that affect both the current activities and the development of HEIs. On the other hand, scenario analysis can be used to formulate and evaluate the strategy of a higher education institution, which is especially valuable in an unstable economic environment. In today's educational reform environment, there is a need to ensure the profitability of private educational institutions while maintaining the proper level of quality of educational services to students and trainees. To create such conditions, educational institutions are implementing a pedagogical management system that addresses the management of business processes of an educational organization with the least amount of labor, time and resources. In a market economy, business process management is becoming increasingly important to ensure the profitability of higher education institutions [10]. Higher education institutions face the same task as commercial structures, namely: to be competitive, that is, to act cost-effectively, to train quality specialists who meet the requirements of the modern labor market.

1.3. Objective

To investigate the essential ontological analysis of business processes of managing the educational process of a higher education institution on an interdisciplinary basis and management technology as a leading one in ensuring the quality of educational services, taking into account the formation of relevant general and special special competencies in managing the institution on the basis of information modeling of business processes for the electronic document management system. Ontological analysis, as a tool, allows to study the transformation of representations into a formalized set of terms and rules for their use, suitable for automated processing, while the ontology is considered as a knowledge base of a special kind with semantic information.

2. Results

A higher education institution is an open integrated, resource-based socio-pedagogical system, which is characterized by integrity and structure, adaptability, based on information and communication, designed to implement the educational process with the main task of providing

quality educational services that ensure the development and self-realization of the individual, which are necessary for the formation of competitive human capital.

The educational process is a complex object consisting of a large number of disparate subsystems and generally lacking an adequate formal description. The systemic approach allows us to analyze the development and functioning of the educational system, taking into account the requirements of the state, society and citizens in both the short and long term (figure 1).

Risks that occur in the business processes of educational activities:

1. Lack of a long-term plan for the formation of the educational process.
2. The process of curriculum development needs to be updated.
3. Those responsible for curriculum management and the final result of educational services are not defined.
4. Lack of analysis of the effectiveness of the educational process, documented reports on the results of the analysis of the process, identification of process risks, and opportunities for the university for the next period.
5. There is no unified information base on the areas of activity of the university (University Corporate Knowledge Base).

Of particular importance is the optimization of the efficiency of managing the business processes of an educational institution, the practical application of the theory of self-organization of complex ordered systems at the stages of analysis and synthesis of educational services systems of different hierarchical levels, i.e. the synergy of university activities.

Risks of the educational process, which were identified based on the analysis of the university context:

1. Accreditation or licensing files are not formed in time, approved by the Academic Council, and submitted to certification and licensing bodies.
2. Obtaining a license to train specialists in a new specialty after the start of the admission campaign.
3. Obtaining a certificate of accreditation of a new specialty after graduation.
4. Reassessment of the possibilities of the license volume of admission to the new specialty.
5. Insufficient level of qualification of scientific and pedagogical staff, including violation of the regulations for conducting training sessions.
6. Lack of necessary educational and methodological support for teaching the discipline.
7. Lack of textbooks, manuals in the discipline.
8. Absenteeism of students.
9. Non-payment of tuition fees by contract students.

Educational activities of HEIs are realized at the expense of the educational process (figure 2).

In today's world, there is a great deal of interest in big data analysis technologies, which is due to the constant growth in the amount of information that any organization has to manage. The main problem with analyzing big data is that most of the information is presented in a format that does not correspond well to the traditional structured format. At the same time, the data is stored in many different storages. In this regard, the purpose of this paper is to improve the efficiency of big data analysis based on the use of ontology. The primary tasks in analyzing big data are the ability to structure data and generate knowledge independently, based on available data. Since ontology building covers all stages of data structuring, it is proposed to use it as an adequate tool for solving the structuring task. Obtaining new knowledge, which is not explicitly formed by experts, based on available data is an important aspect. To solve the problem of obtaining new knowledge in the analysis of big data, it is proposed to use an ontology with the

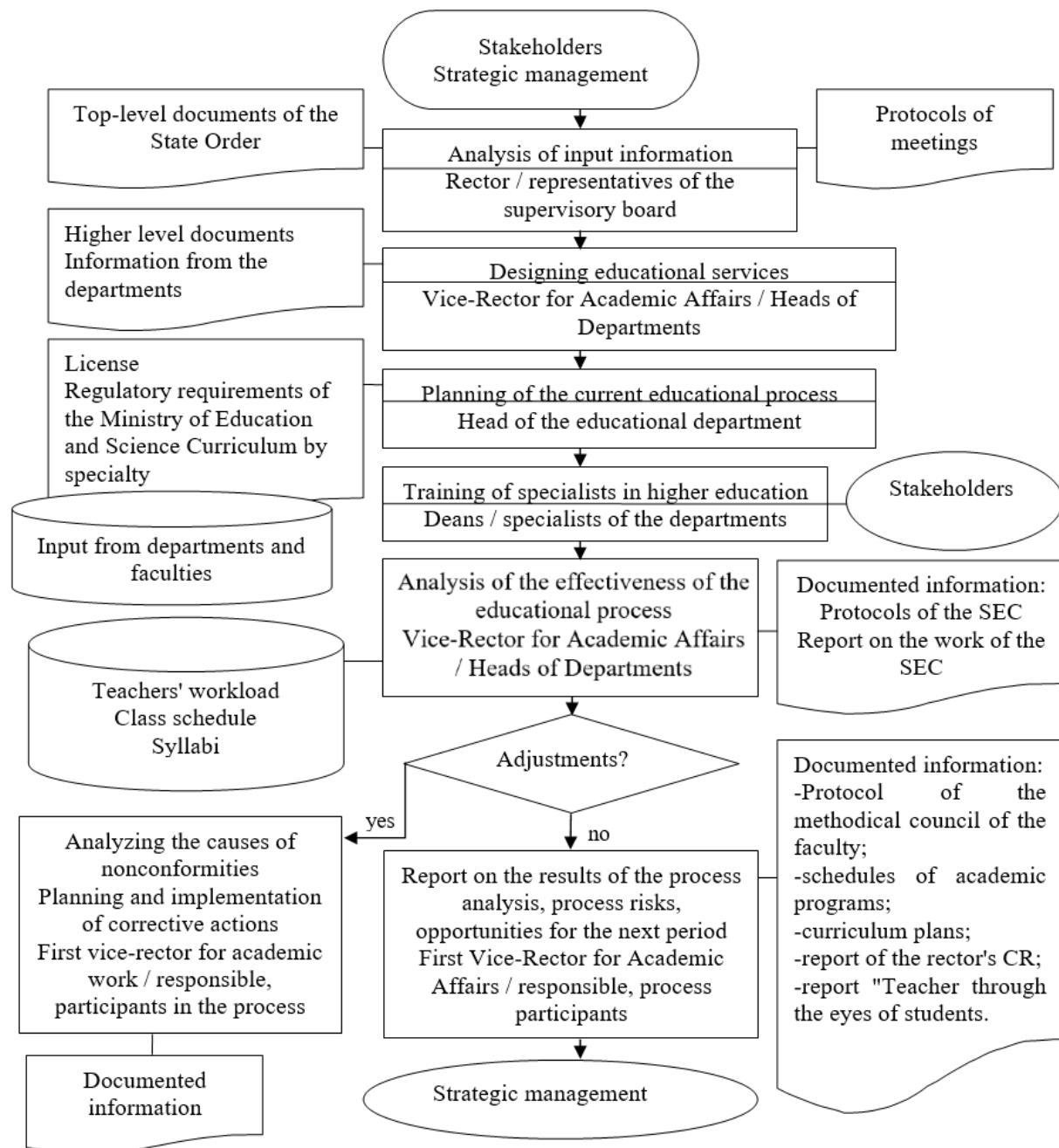


Figure 1. Flowchart of the process “Educational activity”.

use of associative rules. Associative rules allow you to find patterns between related concepts. The algorithms for finding associative rules are based on the concept of a frequent set, which can also be called a frequent set of concepts, a set that occurs frequently. Frequency is simply the number of transactions that contain a given set of concepts. Then frequent sets of concepts are those that occur more often than in a given number of transactions. Thus, using an ontology to analyze big data allows you to effectively extract knowledge from unstructured data, analyze, evaluate, explore knowledge, and gain new knowledge through the use of associative rules.

Higher education institutions are a three- or four-level organizational and technical

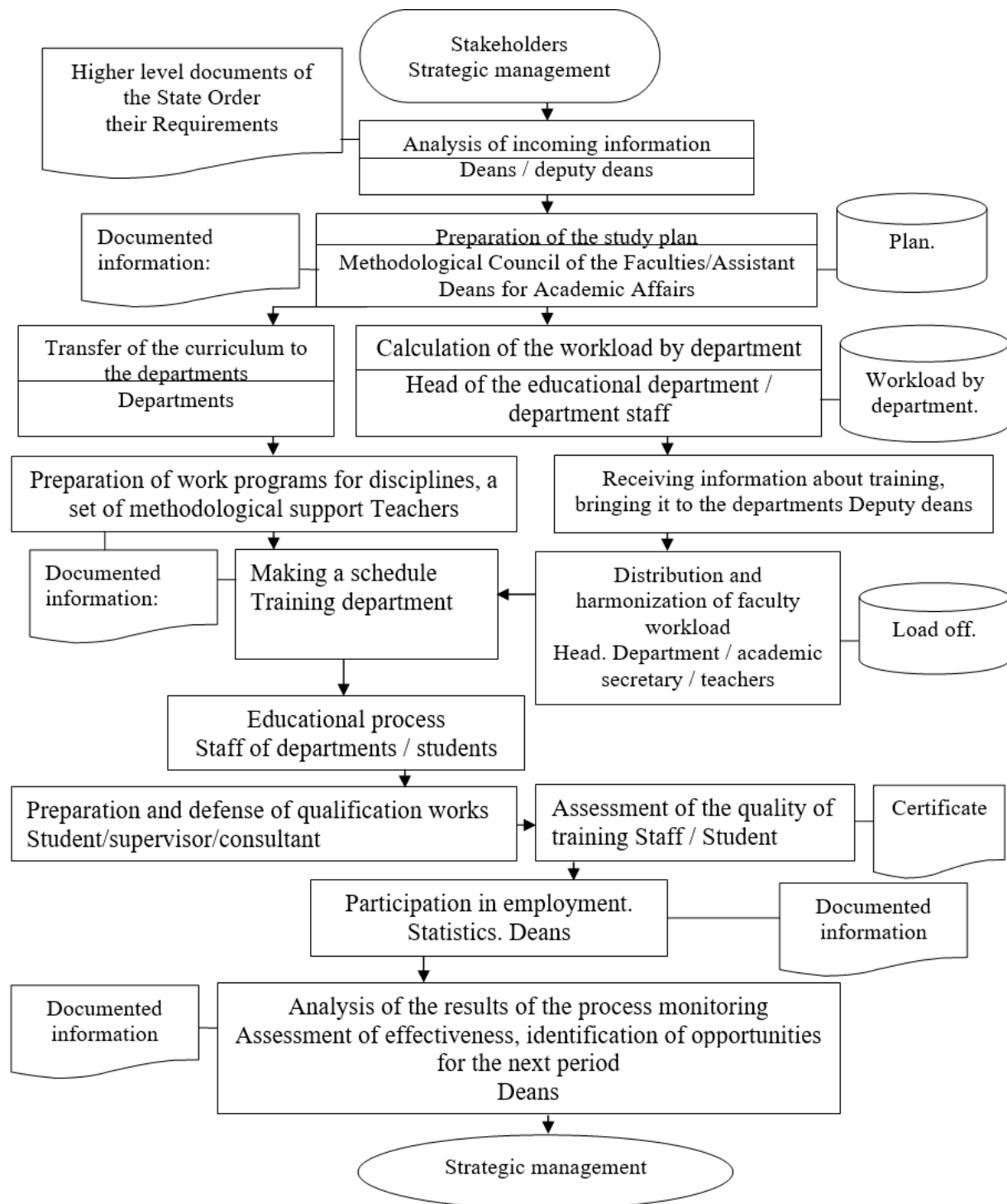


Figure 2. Flowchart of the process “Educational activity of HEI”.

hierarchical structure (institution – faculty – department – laboratory) opened in a market economy. The main tasks of this organizational structure are planning, control, organization and representation in the field of higher education.

The subject of functioning of a HEI is a business entity and an entity of the education system

(students, teachers, support staff).

Object of HEI functioning: students, applicants, teachers, auxiliary technical staff, administrative and economic staff of the administration, dean's office, departments; curricula, syllabi, guidelines, tests and examination recommendations, library fund, computer and technical support.

The periodicity and cyclicity of the functioning of a higher education institution is an academic year, two semesters, vacations, a test session, an examination session, and certification. Training of bachelors (writing diplomas), training of masters (writing diplomas), training of postgraduate students (exams, writing dissertations), training of doctoral students (exams, writing dissertations), course work and projects of students, individual tasks and calculation and graphic works.

Functions of the organizational and technical structure of an educational institution:

- provision of an educational institution;
- administration of an educational institution;
- coordination within the system of the educational institution;
- external coordination and reporting of the educational institution.

The information sources of an educational institution are students, textbooks, lecture notes, methodological recommendations, administrative and economic orders and regulations, provisions, orders and regulations of the Ministry of Education and Science, and laws of Ukraine.

The structure of a higher education institution divides the means of supporting business processes into three levels of management:

1. Basic management business processes (between the administration and the management of faculties or departments).
2. Basic business processes (between the management of faculties and heads of departments or the management of departments and heads of departments).
3. Business processes (between heads of departments and teachers or between heads of departments and employees of departments).

Higher education institutions use systems to manage:

1. The management system of the HEI.
2. Management system of the department.
3. Decision-making system.

As a rule, higher education institutions use a three-tier management structure, namely:

1. Rectorate headed by the rector of the institution.
2. Faculties (institutes) headed by a dean (director) or departments headed by the head of the department.
3. Departments headed by the head of the department or departments headed by the head of the department.

Process (ISO 9000) is an activity that uses resources and is managed to transform inputs into outputs, aimed at creating a predefined output for a specific user, while providing the required process input. A business process is a coherent, integral set of activities implemented in accordance with certain requirements and ensuring the achievement of the required end result for profit, capable of changing depending on market factors. In education, business processes are interconnected educational activities of students and teaching staff aimed at implementing

education standards and training programs to train quality specialists in a particular field of activity. A business process consists of functions that are parts of a business process and can be considered as independent business processes.

The structure of the educational business process organization for higher education institutions is shown in figure 3:

- core business processes on which profit directly depends, such as undergraduate and graduate education or research and development – guest rooms and rental – leasing property.
- service business processes (supporting, ensuring) are business processes that do not generate profit or are costly, such as human resources management, accounting, production and economic activities.

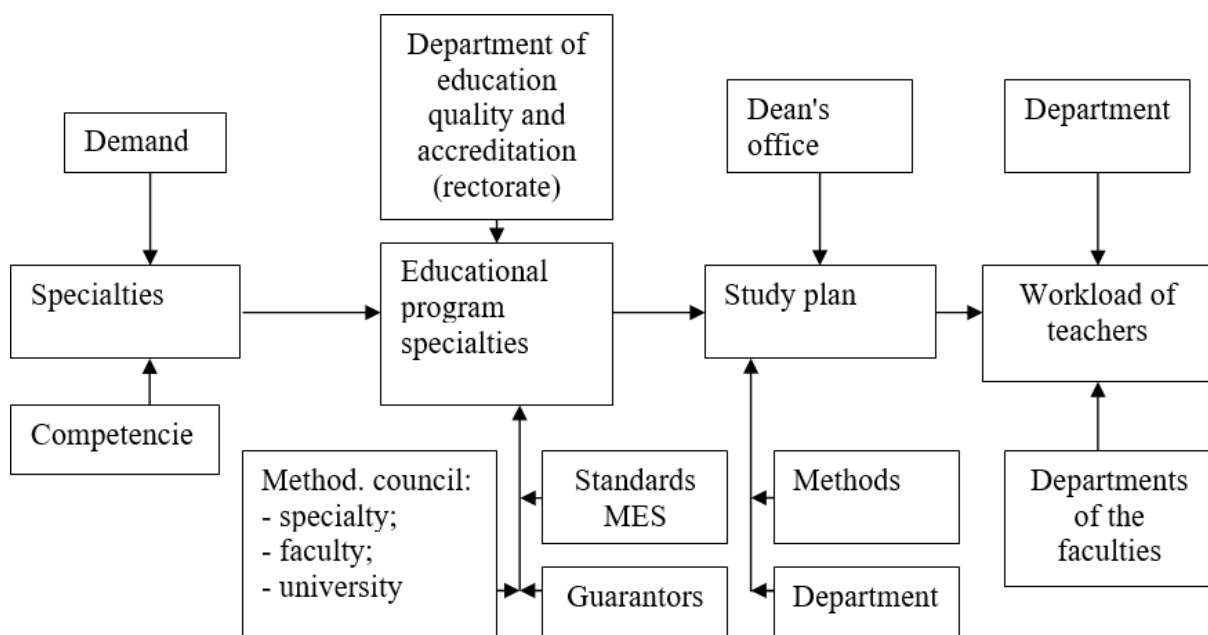


Figure 3. Structure of the organization of the business process of education in higher education institutions.

On a set of business processes, these relations are based on the properties of result formation (by the level of influence on the formation of added value), by place in the value chain, in relation to the organization’s customers, by types of activity, by reference to the management cycle, by functional feature, by the focus of management activity.

A business process description is a statement of the sequence of actions of employees in the performance of certain tasks in graphic and textual form in order to regulate actions in the team, analyze and optimize their sequence [11]. The structures of the main business processes of educational activities are shown in figure 4 – figure 9.

The main business processes of the educational activities of a higher education institution include the process that includes incoming, outgoing and controlling information flows:

- “Management of the student population” (sub-process “Grouping”, sub-processes “Transfer of students to another direction”, “Registration of academic leave”, “Expulsion”, process “Training of students”, sub-process “Control of current academic performance”).
- “Manage the educational activities of higher education institutions” (sub-processes: “Plan the educational process”, “Manage the educational process”, “Control the educational process”).

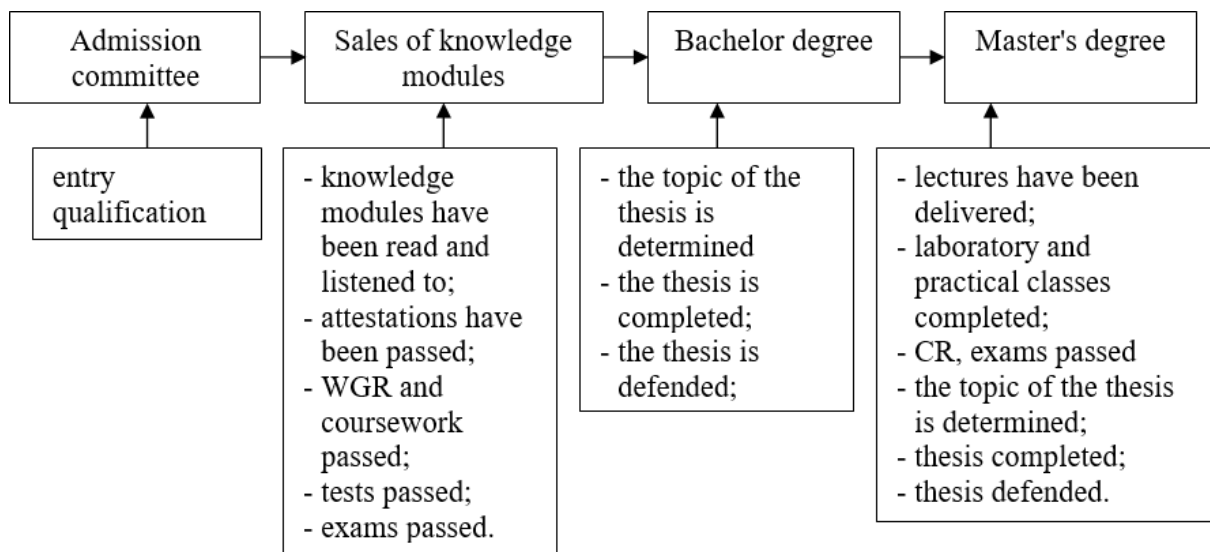


Figure 4. Business process of student training.

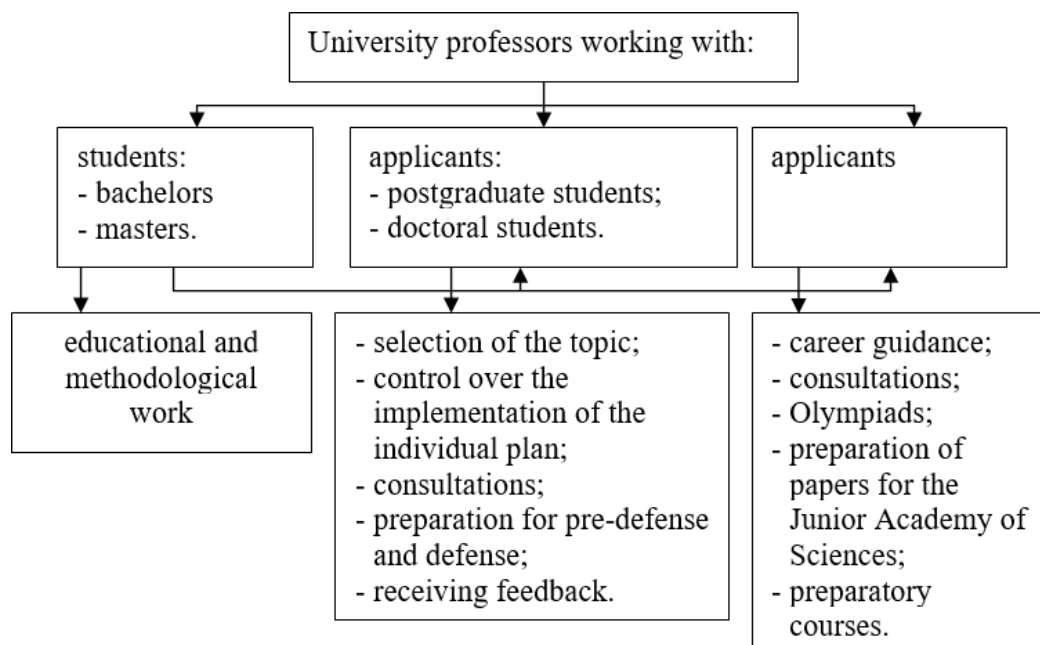


Figure 5. Focus of the business process of training.

- “Manage resources for the implementation of educational activities of the HEI” (employees involved in the business process, information technology and equipment, rector’s office, educational and methodological department, deans and directorates, heads of departments and chairs, teachers, automated information assigned based on qualification requirements).

A separate and crucially important resource is the knowledge module figure 9.

Study of business processes to improve the efficiency of higher education institutions – to study all business processes and build a strategy that will contribute to the growth of all indicators, with a clear assessment of the acquired knowledge and the effectiveness of the institution as a whole. A business approach that begins with understanding the problems faced

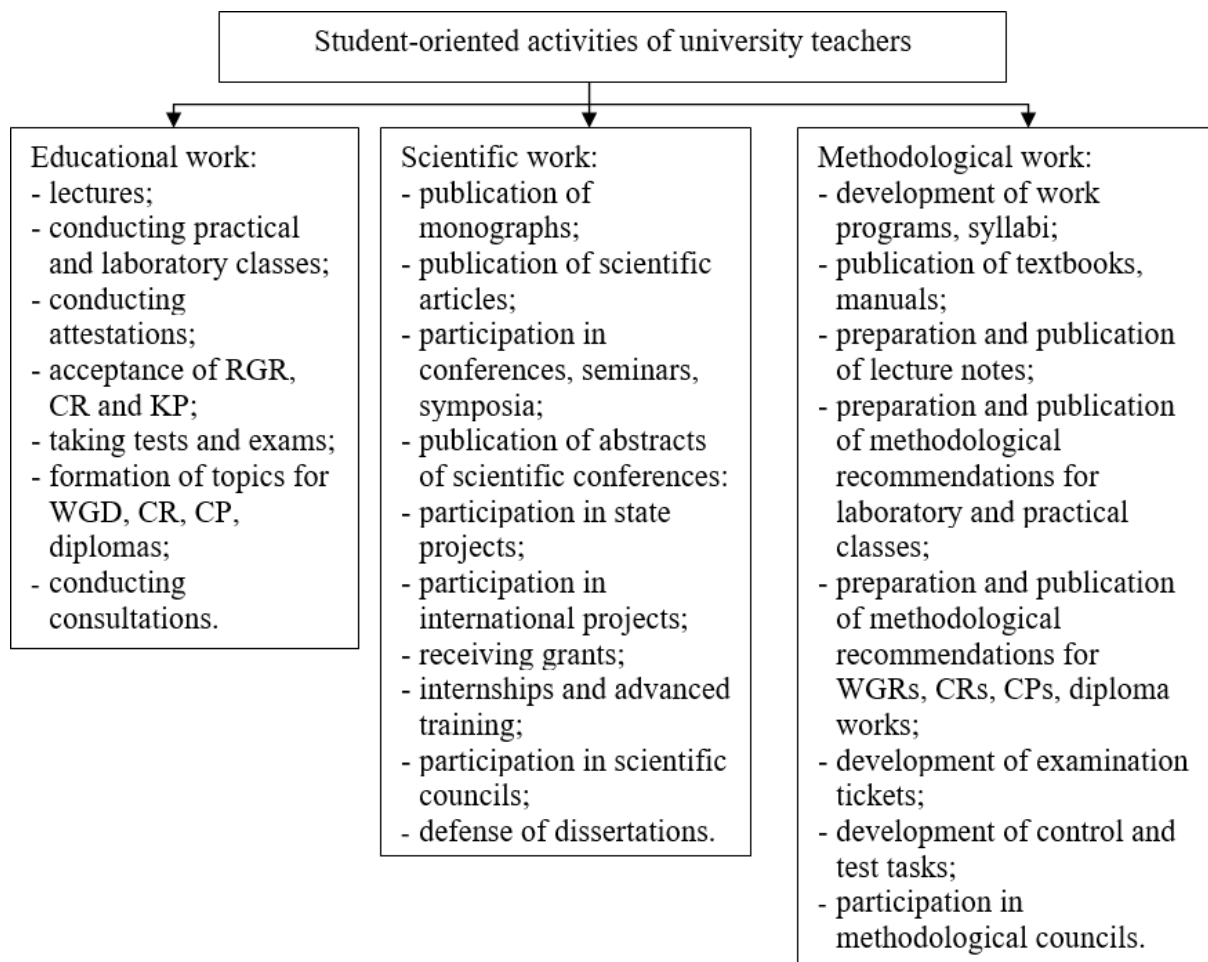


Figure 6. Business process of student-centered training.

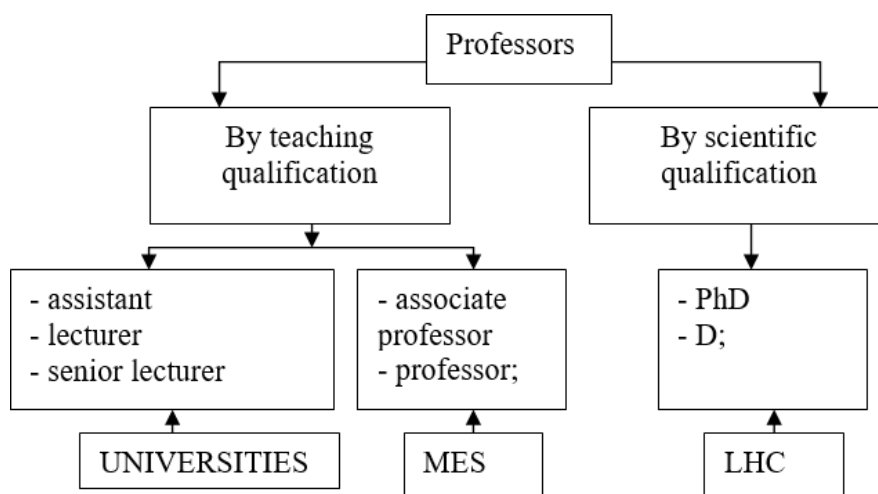


Figure 7. Classification of teachers' competencies.

by the client and finding an effective tool to solve them in a limited labor market [12].
 The main problem is a quality educational product that is consistently profitable.

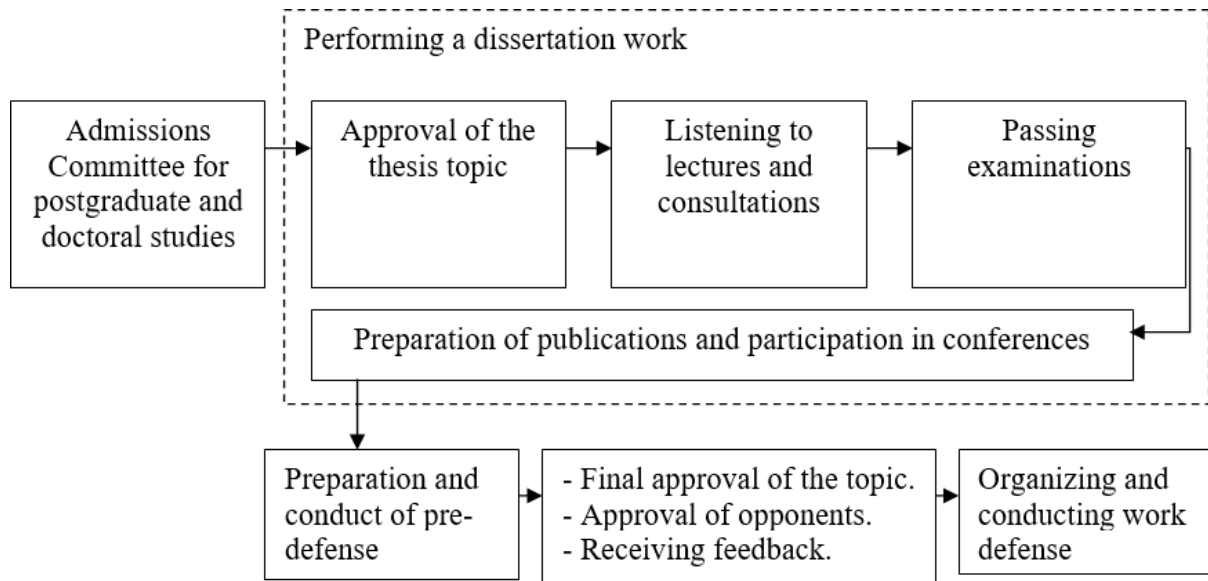


Figure 8. Business process of training teachers' competencies

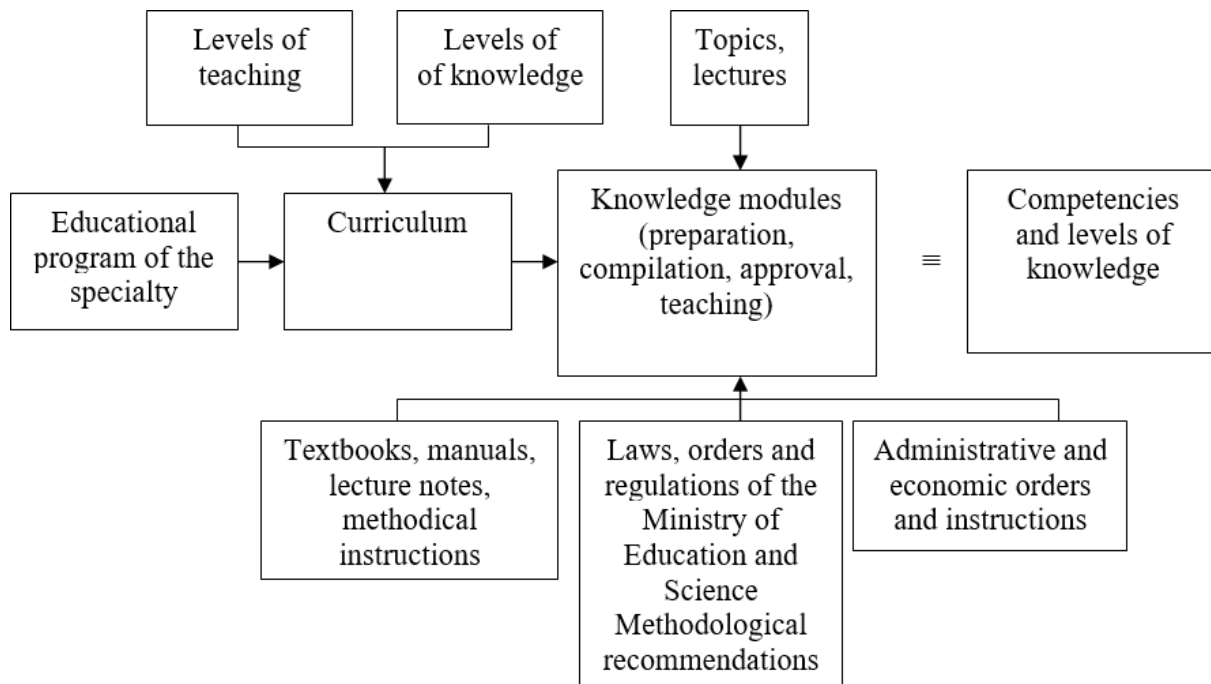


Figure 9. Knowledge modules in business processes in higher education.

Management of the active system of a higher education institution involves building a simulation model of the system's behavior over time under given external and internal conditions, depending on the implemented controlling influence. A higher education institution can influence the factors of the internal environment by implementing a management system. The model of systemic management of higher education institutions is based on the principle of unity of main and auxiliary activities and centralized management. The main activities of the HEI include: educational activities; research activities; production activities. From the perspective of business

process reengineering technology, the main activities of a higher education institution correspond to the main business processes, i.e. a sequence of actions that begins with one or more inputs and ends with the creation of a product or service required by the consumer. In turn, the main activities are divided into subtypes, which correspond to partial business processes. Auxiliary activities that support the implementation of the main activities (core business processes) correspond to supporting business processes that do not have direct access to the customer. The interconnection of core and auxiliary activities is ensured through information support, the functioning of the quality system and a unified regulatory framework. The set of management influences on the main and auxiliary activities (main and supporting business processes) forms the system management of the university.

One of the critical factors is the intensification of information exchange within higher education institutions, given the possibility of one unit participating in different business processes. This task is becoming increasingly important as the amount of information increases and the need for its rational processing.

Correct and adequate creation of information models of business processes becomes the key to the success of the organization in the future.

An electronic document management system is software for working with electronic documents at all stages of their life cycle: creation, editing, and storage. Modern systems support document routing and, of course, basic functions such as search, classification, etc. The organizational structure of an educational institution is based on document flow, which is both directive and informational. Document flow is the movement of documents in an institution from the moment of creation or from receipt from the outside to the moment of transfer to the archive.

An electronic document management system (EDMS) is a software whose main tasks are to organize and support the life cycle of electronic documents: creation, editing, and storage. The document management process also includes workflow – a work sequence within a single business process. In this case, it is the receipt of a document, its approval, and sending.

Modern systems support document routing capabilities and, of course, basic functions such as search, classification, etc. and allow:

- integrate into a single database information on objects such as curricula, teaching load, class schedules, orders, applications, memos, information on control results, data on applicants, students, postgraduates, staff, teaching staff and other objects of the HEI;
- management of the contingent, including enrollment, current academic performance, state certification, internships, military registration, formation of diplomas and supplements, expulsions, to be conducted centrally with the distribution of rights;
- management of the university's economic structures, including dormitories (check-in, registration, eviction, payment for accommodation), to be integrated into a single management system.

3. Conclusions

3.1. Key findings

1. Ontological analysis was successfully applied to model educational business processes in higher education institutions (HEIs) based on electronic document management.
2. A structural approach was used to:
 - study the main business processes of HEIs;
 - analyze the structure, functions, and information flows for organizing and managing educational activities.

3. The research highlighted a shift from employment management to competence management in HEIs, with competence integrating graduate quality characteristics as a category of educational outcome.
4. An ontological model of interaction between subjects and objects of a semantic search system was found to:
 - ensure reuse of knowledge components;
 - provide users with a clear picture of system capabilities and behavior;
 - enable assessment of the system's intelligence level.
5. The model of an HEI was defined as an interconnected and time-ordered set of business processes.

3.2. Practical significance

The process approach demonstrated several advantages over the functional approach:

1. Frees management from operational tasks.
2. Enables creation of templates for action sequences.
3. Implements continuous improvement principles.
4. Directs HEI activities towards business processes and quality systems.
5. Ensures quality in business process implementation technologies.

3.3. Implications for management

1. Formalization and modeling of management business processes facilitate effective decision-making in HEIs.
2. Economic modeling of business process operations can be applied in practice.
3. Analysis of business processes helps identify problems and develop strategies to improve service quality and institutional efficiency.
4. Simulation modeling of the three-tier management structure allows prediction of critical business processes that may:
 - decrease decision-making speed;
 - cause disruptions in HEI functioning and departmental operations.

3.4. Scientific novelty

The research described a model of the educational process as a business process in HEIs, incorporating the electronic document management system. This approach provides a novel perspective on understanding and optimizing educational workflows.

3.5. Future research directions

1. Further exploration of competence-based management in HEIs
2. Development of more sophisticated ontological models for educational business processes
3. Investigation of the long-term impacts of process-oriented management on HEI performance
4. Refinement of simulation models to enhance predictive capabilities for critical business processes

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The poster features a dark blue background with a green circular graphic on the left containing the text 'ECS UNITED' and a stylized 'E' with three vertical bars. The ECS logo and name are at the top right, with the tagline 'Advancing solid state & electrochemical science & technology'. The meeting details are in the center right, and a green circle at the bottom right contains the abstract deadline.

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Study of the usage of STEM technologies in the context of training Ukrainian teachers of computer science in accordance with the social needs and challenges of today

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Abstract. The article discusses the use of STEM technologies in the training of competitive specialists to meet social needs and challenges in the context of the war in Ukraine. The authors analyse the theoretical foundations and the impact of the STEM approach on modern education, focusing on the introduction of STEM technologies in the process of teaching future computer science teachers. The significance of STEM education as an important trend due to its natural science component and innovative technologies is discussed. The key components of the model of teacher training in STEM are identified, such as target, content, activity, evaluation and result. In order to verify the proposed model, an experimental study was conducted to determine the indicators of students' attitude towards STEM technologies. The necessity of ensuring a high level of teacher qualification for the effective formation of STEM knowledge and skills, as well as solving practical problems of various levels of complexity, is substantiated. The article determines how modern STEM technologies can meet social needs and challenges, especially in times of war. The authors aimed to identify strategies and approaches for the effective use of STEM technologies in education, which will ensure the competitiveness of Ukrainian specialists.

1. Introduction

The development of modern society has led to an increased demand for specialists in high-tech industries. These professionals must possess comprehensive scientific and engineering skills. Currently, these requirements are being met within the STEM educational field, which is recognized as a pedagogical innovation of the 21st century [1, 2]. Against the backdrop of global changes in the modern world, education is becoming a key factor in economic, social, and technological development. Therefore, the development of STEM education (science, technology, engineering, and mathematics) in Ukraine is defined as a priority area aimed at training competitive specialists capable of meeting modern challenges [3, 4].

The development of STEM education in Ukrainian educational institutions has its beginnings in the reforms of the 21st century. The introduction of new standards and programs aims to promote the in-depth study of natural and exact sciences, defining a new paradigm of education.



Interactive methods, laboratory work, and project-based learning are becoming key stages in the formation of scientific and technical competence among the younger generation [5–10].

2. The literature overview

The scientific literature extensively covers the pedagogical challenge of training future STEM teachers [11–14]. However, modern challenges and the needs of the digital society have introduced new qualitative aspects to this issue. These challenges stem from the rapid introduction of technology, the increasing social demands during times of war for technological literacy among all individuals, regardless of their professional orientation, and the growing demand in the labour market for technical and engineering specialists. Integrating STEM technologies into the educational process of educational institutions can address the educational needs of the current generation of young people.

Barlow and Brown [15], Fung [16], Ortiz-Revilla et al. [17] consider various educational approaches to educate young people who can solve real-world problems in line with social needs and the challenges of today while developing skills in advanced technologies. Scientists pay special attention to initiatives aimed at improving STEM education and developing models for education reform. STEM education is most effective when implemented at different levels: formal, non-formal, and informal.

Currently, online elements are crucial in the development of STEM education, allowing students to learn at their own pace and convenience. According to Wu et al. [18], many online educational resources offer interactive and visual components that cannot be replicated in traditional classroom settings.

Researchers in Ukraine are working to improve e-learning STEM courses and platforms to provide more effective and accessible distance STEM education. Barna and Kuzminska [19] highlights the peculiarities of teaching STEM disciplines, specifically the need to use specialized hardware and software. The study analyzes different approaches and presents specific examples of STEM education implementation, including models of traditional, blended, and distance learning. The authors argue for the modification of existing STEM education models to ensure quality education in uncertain conditions. They propose a model of behaviour for STEM teachers that considers the instability of the educational systems.

STEM education is a crucial area of educational reform in the 21st century. Educators face a constant need to adopt new teaching strategies and methods to successfully implement STEM education. According to Buturlina [20], Chen et al. [21], Laursen [22], Lindgren and DeLiema [23], Spirin et al. [24] the definition of STEM education varies significantly among educators, educational researchers, curriculum developers, educational policies, and STEM-oriented learning environments.

The integration of digital technologies, including elements of artificial intelligence, into the educational environment is currently viewed as a promising avenue for enhancing teacher training. According to Papadakis et al. [25], it is important to continue researching the development of appropriate models and design methods. Additionally, the use of an educational environment with elements of artificial intelligence is crucial for implementing these achievements in the educational process.

Creating a favourable STEM educational environment integrates pupils and students into collective interaction and actively introduces modern tools and technologies. The need to develop and implement conceptual and practical frameworks aimed at improving the quality of education in the context of STEM is determined by evidence of this trend. This promotes the emergence and development of effective educational models and methods aimed at improving the effectiveness of their learning [26,27].

According to Balyk et al. [28], STEM centres are crucial in establishing a conducive environment for STEM education and implementing STEM initiatives. They provide

coordination, support, and development for such initiatives. The main functions of a STEM center, according to the authors, include developing and improving STEM programs, providing pedagogical support to teachers for implementing innovative teaching methods and using modern technologies, creating infrastructure to support student research, projects and competitions, and organizing scientific events. All of these functions collectively contribute to the successful implementation of STEM education at the university and the training of highly qualified STEM teachers. STEM centres play a crucial role in fostering innovation and development in STEM education.

Some studies [29–31] focus on enhancing teaching methods and developing better approaches to teaching STEM subjects. STEM education is an academic field that incorporates an augmented natural science component through the use of innovative technologies. According to researchers, the training of future teachers in natural and mathematical disciplines for the implementation of STEM technologies is based on the active use of activities aimed at implementing STEM projects, Learning StartUps, and experiential learning [32–34].

To enhance the effectiveness of STEM students' learning, Hrybiuk [35] investigates the potential of using computer-oriented methodological systems of natural science and mathematics research learning (COMSRL) components to design variable models of research learning. The author's experimental research confirms that the use of COMSRL contributes to the optimal concentration of educational resources and the integration of proven robotics courses into the educational process and extracurricular activities. The organization of content and STEM technologies aims to prepare students for research work and their industrial integration in the educational process. The experiment results identified the most effective psycho-pedagogical factors that influence STEM knowledge acquisition. When considering the feasibility of applying and selecting COMSRL components, the author recommends giving preference to those that contribute to the development of conceptual knowledge structures in students.

The scientific and theoretical foundations of using robotics in education are discussed by Morze and Strutyńska [36]. They acknowledge the significance of incorporating educational robotics in STEAM education to enhance students' STEM competencies. This approach prepares individuals for implementing socially significant projects, enhances the practical value of theoretical knowledge, broadens scientific outlook, and promotes successful adaptation in a digital society. The authors have identified a set of STEM competencies necessary for successfully applying robotics in students' future professional activities. According to the researchers, the most important competencies are integral STEAM competence in the field of robotics, research competence, digital competence, and soft skills.

Stimulating social interaction among future teachers in a professional environment is an essential aspect of the learning process. This facilitates the formation of collective experience, the exchange of ideas, and the sharing of best creative practices in STEM education [37]. During their training, the interdisciplinary aspects of STEM/STEAM education [38] are emphasized. Various complex methodological support and elements of STEM technologies, such as robotics [39], microcontrollers [40], embedded systems [41], 3D technologies [42], 3D printing [43], artificial intelligence [44], machine learning [45], drone science, or the study of drones (unmanned aerial vehicles) [46], VR [47], and AR [48] are used in the educational process. This enables the preparation of specialists for modern challenges and the implementation of STEM technologies in various educational institutions.

Significant progress has been made in researching the theoretical and methodological foundations of STEM education, including the design of immersive technologies. Immersive technologies are a significant component of STEM technologies, providing innovative tools for learning and research in various fields [49–52].

The new generation of educational systems is characterized by a higher level of adaptability compared to previous automated learning tools [53]. This is accomplished by creating a

flexible and open educational environment that utilises hybrid cloud solutions, augmented and virtual reality technologies, and elements of artificial intelligence [54]. These technologies offer personalised services at both the individual and collective levels.

Semerikov et al. [55] analyse various approaches to understanding concepts such as “immersiveness”, “immersive educational environment”, “immersive approach in education”, and “immersive educational resources” (IER). Authors consider the pedagogical aspects of using immersive environments in teaching and classify research on immersive education. Additionally, this paper analyses the key elements involved in designing and implementing multimedia electronic displays (MED). It defines the fundamental principles of MED design and outlines the methodology for its implementation in educational settings. The paper also examines the general model of the methodology for designing IERs, which includes the goals, objects, methods, stages, and content of training, as well as the forms of organization of the educational process, teaching aids, and expected results of the methodology. The article proposes elements for designing immersive educational resources, specifically a comprehensive immersive educational development in the form of a distance course. It also considers examples of designing prototypes of immersive learning materials and other innovative approaches.

According to the literature analysis [56–58], the use of AR and VR in STEM education provides numerous opportunities for learning concepts and acquiring scientific skills. At the same time, it is necessary to balance the positive effects of these innovative technologies with the related risks to enable a critical and conscious use of them. These works provide a methodological basis for further research in this area, particularly in the context of using STEM technologies for the professional development of teaching staff.

3. Theoretical background

The training of future school teachers is crucial for many European countries, including Ukraine. Ukrainian universities acknowledge the significance of training highly qualified STEM professionals and are adopting innovative teaching approaches. An urgent task is the development and implementation of new bachelor’s and master’s programmes aimed at enhancing research skills.

The research focus of this article is to study the use of STEM technologies in the context of training competitive specialists to the social needs and challenges of today. The results of the study can serve as a basis for further discussions and improvement of educational practices aimed at forming specialists who can effectively cope with modern social challenges and needs.

The research goal is to study the main trends in university STEM education; to identify the key components of the model of training teachers in STEM, to study the use of STEM technologies in the context of training competitive specialists by the social needs and challenges of today in times of war.

Research methods. The research methodology covers various aspects of the use of STEM technologies in the process of training competitive specialists. The authors used the following research methods: analysis of primary sources, designing a model for STEM-oriented training of future computer science teachers, a questionnaire to determine the effectiveness of using STEM technologies in training competitive specialists, and factor analysis to identify the mutual influence of the model components.

The main trends in Ukrainian university STEM education are as follows.

- Virtual laboratories. There, students can conduct experiments and research in an online environment, developing skills and knowledge without the constraints of traditional laboratory conditions.
- Interdisciplinary integrated courses. They combine elements of various STEM disciplines to promote integrated learning and the development of complex solutions;

- Cooperation with world universities. The organisation of joint programmes and projects with global universities provides an opportunity to create an international environment for learning and exchange of experience.
- Robotics and drone programming. This approach is implemented through courses and workshops on robotics and drone programming to teach students modern technological and engineering skills.
- STEM projects with a social focus. The implementation of such projects is aimed at solving social problems using STEM technologies, which contributes to the development of responsibility and social awareness of students.
- STEM laboratories and STEM centres. In these centres, students can use advanced equipment and technologies for their own research and projects.
- Internships and employment in IT companies. The organisation of internships and practice programmes for students in large IT companies enables future specialists to apply theoretical knowledge in practice.
- STEM mentoring programmes. This approach involves providing support from experienced STEM professionals and guiding students in developing their professional skills;
- STEM incubators and start-up centres. The trend is implemented by creating an infrastructure for start-ups and innovations, where students can implement their ideas and develop their own STEM projects.
- STEM festivals and conferences. These are places where students can demonstrate their achievements, share experiences and interact with representatives of well-known companies and academic institutions.

These ideas aim to encourage a creative approach to STEM education in Ukrainian universities and promote student innovation in these fields. The introduction of STEM education in educational institutions has resulted in increased student interest in the natural sciences, as well as an increase in the number of university problem groups and competitions. STEM laboratories, technology parks, and educational centres provide opportunities for in-depth study of subjects, experimentation, and a creative approach to learning.

Ternopil Volodymyr Hnatiuk National Pedagogical University (Ukraine) is also implementing STEM approaches in its educational process. The Faculty of Physics and Mathematics trains future computer science teachers using STEM approaches, and there is a STEM centre to support STEM disciplines.

We propose the model for future computer science teacher training in STEM at Ternopil Volodymyr Hnatiuk National Pedagogical University. The key components of the model are follow:

- Educational training. This component covers professional education, including educational bachelor's and master's programmes "Secondary Education (Informatics, Mathematics, STEM Education)". Teachers with interdisciplinary knowledge in various STEM fields can more easily integrate different subjects and create more holistic lessons.
- Pedagogical skills. This element focuses on the development and use of effective teaching methods that stimulate interest in STEM subjects. Innovative pedagogical approaches, such as project-based learning, robotics, and game-based approaches, are also discussed.
- Preparation for the use of technology. It involves training teachers in the use of modern technologies to improve the learning process and engage students, as well as developing digital skills for students to effectively use information and communication technologies.
- Support for research activities. The component includes the stimulation of scientific research through the creation of a STEM research centre, support for future teachers in conducting

research in their chosen STEM field, and involvement of students in scientific and practical projects.

- Cooperation with the public and various institutions. It is essential to increase the intensity of communications on STEM education, promote ideas about STEM education among the public, and facilitate the professional development of teaching staff and specialists involved in the educational process.

These components create a model of teacher training in STEM to form highly qualified teachers capable of stimulating students' interest in science and technology (figure 1).

During wartime, the authors adapted and modernised the curricula of bachelor's and master's degree programmes, identified the current state of STEM curricula, and highlighted key topics that need to be adapted to the war. The theoretical material was updated to accommodate limited resources, and practical examples from real life were added. Here are examples of specific courses, STEM technologies and methodologies that have been introduced into the educational process.

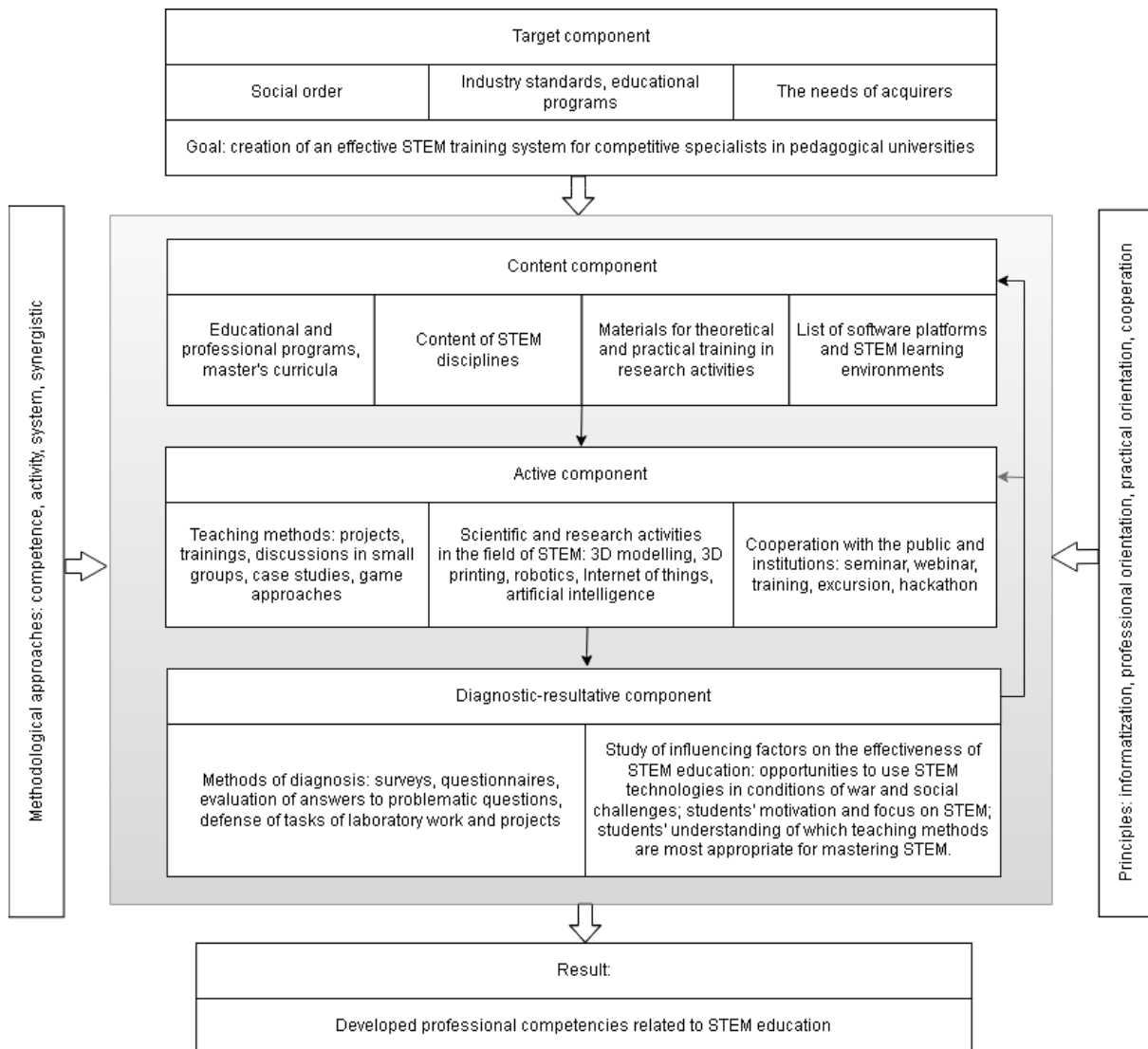


Figure 1. A model for STEM-oriented training of future computer science teachers.

Courses offered include “Methods of Teaching Computer Science and STEM Education Technologies”, “STEM Projects”, “Fundamentals of Robotics”, “Fundamentals of Cybersecurity”, “3D Modelling”, “3D Printing”, and “Computer Networks”. *STEM technologies* covered include programming, 3D modelling and 3D printing, robotics, IoT, virtual reality, artificial intelligence, and VR/AR.

Educational, methodological and technical support for STEM education are e-courses “STEM projects”, “Methods of teaching computer science and STEM technologies”, “Fundamentals of robotics”, “E-learning technologies”; technical equipment of the STEM centre.

Methods of conducting classes. Creative teaching methods: stimulation of creativity, development of students’ creative skills in solving practical tasks, projects, search and implementation of methods that promote the development of students’ creative abilities, use of alternative materials for practical demonstrations, methods of developing critical thinking.

4. Study results and statistical processing

To investigate the effectiveness of using STEM technologies in training competitive specialists, we created a questionnaire. The respondents were 45 first- and second-year master’s students enrolled in the “Secondary Education (Computer Science, Mathematics, STEM Education)” program. Of these, 48.9% were female and 51.1% were male.

The questionnaire comprised multiple question groups. They were formed in the form of a 5-item Likert scale and determined indicators of students’ use or attitude towards STEM technologies, such as:

- frequency of use of STEM technologies such as programming, robotics, 3D printing, and IoT;
- the benefits of using STEM for gaining knowledge, developing practical skills, innovation, creativity, and critical thinking; difficulties in using STEM, including lack of time and lack of interest or knowledge;
- the effectiveness of using didactic methods in STEM education; Relevance of some STEM technologies (programming, robotics, 3D printing, IoT, aerospace devices) for solving problems related to war;
- students’ goals in studying STEM, including getting some knowledge, skills development, having fun, and getting a degree;
- using STEM in future professional activities including for teaching, scientific or practical work, to solve some social problems and to develop own career.

To reduce the number of variables in the factor analysis, average values were calculated for the variables listed above. The survey data can be accessed via URL: <https://drive.google.com/file/d/188vI7AzyGo-eYsDoHzTswULBAuQgKuB6/view>.

Exploratory factor analysis was used to verify the selection of criteria groups [59]. This method can also reveal other factors, such as latent correlations between certain indicators in the survey. This means that the variance of a large number of variables in our dataset can be described by a few summary variables, i.e. factors [60]. It is assumed that some of the latent variables coincide with the question groups in the survey. The search steps are repeated until a smaller number of factors is reached. The statistical data was processed using libraries from the R language, such as psych, nFactors, and corrplot.

From the CSV file in the sel_data dataset, we selected the required fields (AverageScoreSem, FrequencyUsingSTEM, LevelMasterySTEM, InterestInSTEM, AdvantagesUsingSTEM, SelfReadinessUsingSTEMSolveProblemsRelatedWar, STEMImportanceOvercomingWarConsequences, EffectivenessTeachingMethodsSTEM, UsingSTEMInFutureProfessionalActivities).

Then, the eigenvalues were calculated from the sel_data numerical dataset (list) which was processed as a correlations vector. Using the fa.parallel() function, we analysed the number

of factors to be retained in the subsequent factor analysis. Factors with an eigenvalue greater than or equal to two were selected as significant. There were 3 such factors. Additionally, the dependence of the number of factors on the eigenvalues from the vector of correlations is shown in figure 2.

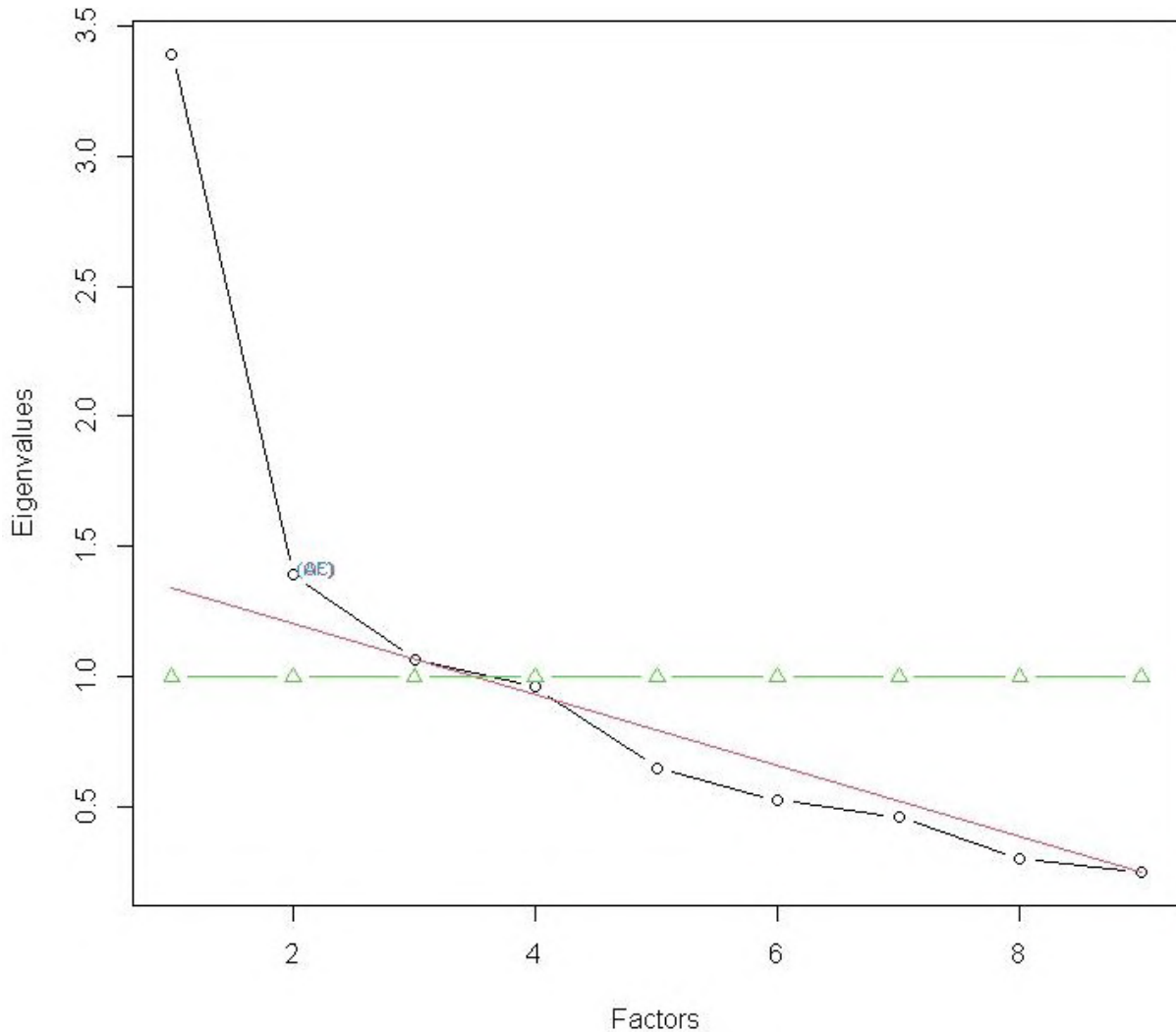


Figure 2. Determining the number of factors to analyse.

If we look at figure 2, the black line shows the eigenvalues of the actual data, while the green and red lines show the modelled and sampled data. Here we can see the large drops in the actual data and the point where they intersect. The gap between the modelled and actual data tends to be minimal near the point $x = 3$. This is the desired minimal number of factors. The graphical method indicates that a four-factor model is also acceptable. However, based on the eigenvalues, we will concentrate on three factors.

To conduct the factor analysis, we utilized the `factanal()` function from the `psych` package [61]. The code used for performing factor analysis on the three-factor model is shown below.

```
fit<-factanal(sel_data,3,rotation = 'oblimin')
print(fit , digits=2,cutoff=0.33,sort=T)
```

The function's arguments were utilised, with 'sel_data' representing the correlation matrix,

'3' indicating the number of factors to extract, 'oblimin' as the rotation method (it is assumed that there is a correlation between the factors). The obtained results are presented in the table 1.

Table 1. The results of factor analysis using method maximum likelihood

Variable	Factor ML1	Factor ML2	Factor ML3
FrequencyUsingSTEM			0.50
LevelMasterySTEM			0.67
InterestInSTEM			0.76
AdvantagesUsingSTEM			0.65
UsingSTEMInFutureProfessionalActivities			0.66
STEMImportanceOvercomingWarConsequences	0.57		
SelfRreadinessUsingSTEMSolveProblemsRelatedWar	1.00		
EffectivenessTeachingMethodsSTEM		0.99	
AverageScoreSem			

We can see that our model is simple because it requires a single load of each variable. The last section of the factanal() function output shows the results of a hypothesis test. The null hypothesis, H0, is that the three factors in our model are sufficient to capture the full dimensionality of the data set. In our case, the p-value exceeds 0.75, which is greater than 0.05.

Therefore, we have no reason to reject the null hypothesis. In the three-factor model, the variable AverageScoreSem from the last row of the table 1 is insignificant. This indicates that there is no relationship between the use of STEM technologies in education, students' attitudes towards STEM technologies and their academic performance. This variable also gives a large uniqueness, sometimes referred to as noise, which corresponds to the proportion of variability that cannot be explained by a linear combination of the factors [62]. It is therefore not included in the model.

The first factor (ML1) consists of two variables. It relates to the war that is currently taking place in Ukraine. Students see opportunities to use STEM technologies in these difficult conditions. It can be reasonably assumed that they know what projects and skills need to be developed in students now. In addition, they must be ready to use STEM technologies in the process of rebuilding Ukraine. The second variable that forms the factor indicates the civic position of students, and their willingness to resist the occupiers.

The variable EffectivenessTeachingMethodsSTEM forms the second factor (ML2) of the model. We interpret it as responsible for creating an educational environment. We call it the STEM ecosystem. This factor demonstrates students' understanding of which teaching methods are most appropriate for mastering STEM.

Five variables such as FrequencyUsingSTEM, LevelMasterySTEM, InterestInSTEM, AdvantagesUsingSTEM and UsingSTEMInFutureProfessionalActivities form third factor (ML3). This factor describes students' motivation and focus on STEM. It indicates their interest, understanding of the benefits and readiness to use relevant technologies.

Thus, as a result of the analysis, we highlight the following factors:

- Factor ML1: The value and importance of STEM to solving problems related to war.
- Factor ML2: Effectiveness of the STEM teaching model and methods implemented by the university.
- Factor ML3: Development and application of professional competencies related to STEM education.

In general, all factors show that modern STEM education must meet the challenges of today. We processed the sel_data list using the function fa.

```
ml3<-fa(sel_data, nfactors = 3,
        rotate = 'oblimin', fm = 'ml')
```

We obtained similar data on the number of factors and the distribution of variables within them. The same function returned data indicating the statistical adequacy of our model, such as

- RMSR=0.05. It is the root mean the square of residuals. This is acceptable as this value should be closer to 0.
- RMSEA \leq 0.001. It is the root mean square error of approximation. Its value shows a good model fit as it is below 0.05.
- TLI=1.15 (the Tucker-Lewis index). This is an acceptable value because it exceeds 0.9.

Visualisation of the relationships between the factors of our model was obtained using the fa.diagram() function. It is shown in figure 3.

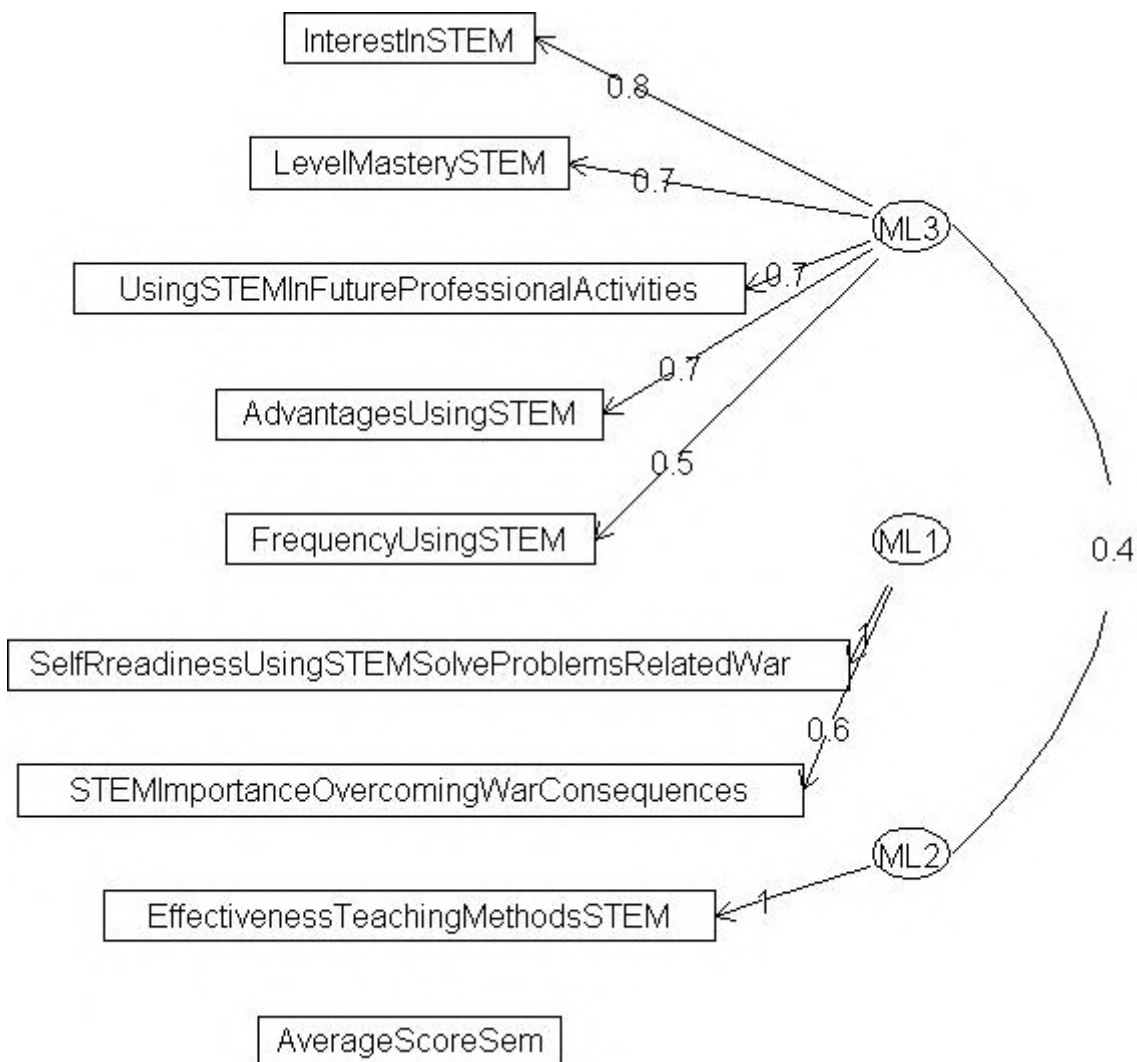


Figure 3. Relationships between the factors of the model.

5. Discussion

In today's world, the issue of training competitive specialists is becoming a critical task for educational institutions. In this context, great importance is attached to the use of STEM technologies as modern pedagogical tools aimed at improving the efficiency of the educational process. Based on the developed model for future computer science teacher training in STEM (figure 1), we can state that the factors identified through the questionnaire have some relationships to the components of the model. Let's analyze these relationships.

Factor 1 (ML1) captures students' wartime experiences and their understanding of the role of STEM technologies in Ukraine's current situation. It combines students' opportunities to use STEM technologies in these difficult conditions and their civic position and willingness to resist the occupiers. In particular, this factor aligns with the social order in the Target component of the model. It considers industry standards, educational programs and the needs of acquirers. In the context of Ukraine's wartime situation, STEM education must equip future teachers with the skills to address the country's specific needs and challenges. Therefore, we offer students to master technologies that ensure the resistance of Ukrainians, such as robotics, drones, 3D printing, etc. The content component of our model emphasizes the importance of content that aligns with educational and professional programs as well as the content of STEM disciplines. The first factor (ML1) highlights the need to integrate the wartime context and the role of STEM technologies into the curriculums. This factor connects to the teaching methods from the Active component, which emphasizes project-based learning, scientific research activities, and cooperative learning approaches. Experiences working on real-world problems, which could address the challenges Ukraine faces, could be a powerful way to engage students. The first factor (ML1) does not directly connect to the assessment methods outlined in the model. However, student experiences during wartime could be a valuable source of data to inform the development of curriculum and teaching methods.

Factor 2 (ML2) focuses on effective teaching methods of STEM disciplines. It aligns with the model's Content component and Active component which emphasize effective teaching methods for STEM education. The model suggests that the content of STEM education programs should include scientific research and practical training activities. Factor 2 highlights the need for teachers to understand how to use these methods to create an effective learning environment. The second factor directly relates to the teaching methods, which outlines specific methods for STEM instruction such as project-based learning and scientific research activities. The diagnostic and result component of the model identifies methods for diagnosing the effectiveness of STEM education, including surveys and evaluation of student work. These methods could be used to assess students' understanding of how to create an effective STEM learning environment.

The factor 3 (ML3) captures students' motivation and focus on STEM. It aligns with the model's overall goal of training competitive specialists and the content component's emphasis on educational and professional programs. Students' motivation and focus on STEM are important indicators of their potential to be successful teachers. The model suggests the content of STEM education programs should be tailored to student interests. Understanding students' existing motivation and STEM focus can inform new curriculum development. The model suggests using of active learning methods such as project-based learning. Students who are more motivated and interested in STEM are more likely to benefit from these types of activities. This is evidenced by the value of LevelMastery STEM variable. The diagnostic and result component of the model allows the use of various sets of methods for diagnosing the effectiveness of STEM education, including surveys and evaluation of student work. These methods could be used to measure student motivation, they learning progress and STEM focus.

In accordance with it, we have changed the educational programmes, the content of individual modules, the requirements for students' skills, and the organisation of the educational process itself. The main objective of the model is to make education relevant to our time. In this

context, there are some ways to improve the educational process through the introduction of STEM technologies in the training of future teachers. For example, they include the following

- expanding the experience of using Learning StartUps to increase students' motivation for other disciplines, such as programming, information technology, robotics, etc;
- studying gender equality, namely the wide involvement of girls and women in the IT sector, in particular in STEM education;
- inclusion in the design of art and design components of a scientifically based methodological system for teaching various disciplines, including the basics of robotics and 3D technology, as a component of STEM education;
- inclusion of certain components of Learning StartUp in the student's graduation work.

6. Conclusions

The war in Ukraine is a global challenge to democracy, food security, economic stability and international law and order. It has stimulated the development of technology in Ukraine, particularly in the areas of defence, energy, medicine and information security. A successful response to these challenges requires specialists who not only have deep knowledge in their field, but are also capable of interdisciplinary cooperation, data analysis, use of modern technologies and creative solutions.

One way to train such specialists is to use STEM technologies in higher education. For future computer science teachers, we recommend learning the basics of robotics, programming, 3D modelling, drone technology, etc. Ukrainian students should take part in research projects aimed at developing new technologies for the army, infrastructure rehabilitation, energy efficiency, healthcare, etc. Thus, STEM technologies can contribute to the training of competitive professionals who will help overcome the social challenges associated with the war in Ukraine.

The results of this study demonstrate the effectiveness of the STEM teacher training model and the use of the latest pedagogical methods. This approach makes it possible to identify effective learning and skills development strategies that will provide graduates with the ability to innovatively solve problems of varying levels of complexity, given the high level of qualification requirements and the demands of society. As a result of the synthesis and generalisation of the analytical work, recommendations have been developed on the areas of application of modern advanced STEM technologies for the training and professional development of computer science teachers. The results of the study can serve as a basis for further discussion and improvement of educational practices aimed at training specialists who can effectively cope with modern social challenges and needs.

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The implementation of STE(A)M education through Scratch projects

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Abstract. The present research is motivated by the necessity of introducing modern methodologies corresponding to the study's content into the educational process. The work aims to use Scratch projects for the organization of students' educational activities, as well as for their creative self-realization. Authors realize STE(A)M-approach in the educational activity by facilities of Scratch-projects. The high-level block-based visual programming language could be an auxiliary technology for a teacher and an independent developing tool for students. The research revealed the main themes that became the basis for the development of the author's course "Creative Self-Fulfilment in Scratch". This contributes to the development of students' creativity. The content of the course is extended with projects in algebra, geometry, physics and musical culture. Each of these projects demonstrates the unity of technology and creativity.

Dedicated to the memory of Professor
Yurii Ramskyi

1. Introduction and problem statement

Is the inventor a vocation, talent, or hard work? Many our students construct robots, work with artificial intelligence, and demonstrate that everybody can become an inventor in the modern world! Development of such intellectual potential is simply only possible with material support and educational reforms (the project integrated studies approach). The importance of this is based on the fact that human activities in various spheres are often based on planning. The skills of independent getting of knowledge, systematization, the knowledge about orientation in informative space, and the ability to catch a problem and decide all become exactly through the project realization. It is efficient to use this method to construct individual education plans for every future specialist. This improves the quality of studies and moves the development of educational technologies forward, primarily related to the STE(A)M technology [1].

STEM education is one of the essential areas of the educational reform of the XXI century. Modern initiatives in the field of STEM require the development of a model for transforming



education that corresponds to the contemporary demands of society. There is a need to transform the existing model of training, first of all, pedagogical staff from classical education to innovative STEM education [2, 3]. Institutions and scholars are searching for new approaches to prepare people for solving real problems of the surrounding world through different STEM approaches in education [4–6].

It is known that STE(A)M is the modern approach to studies that combines natural sciences, technologies, engineering, art, and mathematics. These industries are “professions of the future” that are similarly named. A perspective of STE(A)M education is the development of the talent of students and the stimulation of the appearance of new ideas and skills. It helps them to adapt themselves to the modern world. For the successful realization of an STE(A)M project, such terms are needed:

- presence of a meaningful problem in a creative, research plan;
- clear raising of key and thematic questions;
- practical meaningfulness of the expected results;
- unassisted work of participants;
- structuring of substantial content of part of a project (stages, tasks, distribution of roles, and others like that);
- use of research methods;
- application of computer technologies.

2. Apparatus criticus

The present research is motivated by the necessity of introducing modern methodologies corresponding to the study’s content into the educational process.

The aim of this work is the use of Scratch projects for the organization of students’ educational activities and their creative self-realization.

Achievement of the goal of the research is possible through the decision of such tasks:

1. Analysis of apparatus criticus;
2. A selection of educational resources for an acquaintance with the environment of Scratch;
3. Research of the application of Scratch-projects for the study of mathematics, physics, art;
4. The usage of Scratch-projects for the presentation of own ideas.

The research object is Scratch technology.

The subject of scientific research is the realization of STE(A)M approach in the educational activity by facilities of Scratch projects.

For achievement of the goal here was used the complex research methods: a) theoretical – an analysis of scientific and technical literature, generalization, and design of processes at the study of separate themes from natural sciences; b) empiric – observation, analysis of the experience of the use of technology of Scratch.

Approbation of research realized within the limits of activity of STEM center of the our Faculty.

3. Research results

3.1. Analysis of basic concepts of research

Student-centered learnings the process-oriented to forming such a model of studies in an Institution of higher learning at that essential knowledge, abilities, and skills that the breadwinner of higher education must seize in the process of acquisition of professional competencies are sent to the satisfaction of his own necessities and provide his highly sought at the market of

labor, high capacity for employment. An example of the realization of such studies through the technology of “small steps” can be found in [7].

Providing diverse personality development leads to forming creative, professionally competent social mobile specialists. Only such people can realize themselves in any sphere of activity [8]. To rear a capacity for generating ideas, non-standard decisions possible at a systematic approach and from an early age. Effective for this purpose is the use of Scratch projects [9]. Implementation of activity approach phases is reasonable for an author in the study of informatics using project methodologies in the Scratch environment during the controlled distance studies.

Moreover, results by Cárdenas-Cobo et al. [10] confirmed an acceptable level of satisfaction in the group that used Scratch as a technological tool for learning. This is consistent with certain experiences reported in [11–14].

Computer programming can help children develop problem-solving and analytical skills. Thus, many countries have included computer science in the curriculum of the primary school [15, 16]. The analysis of results shows that pre-service teachers appreciated the collaborative work, the freedom to code an app following their own interests, and the use of engaging software.

An animation programming of the Scratch environment appeared due to the rapid development of educational programmatic products and their competition. The technology combines programming, graphic arts, design, and creativity. In addition, it can be actual, as for schoolchildren and students. The feature of this environment is the possibility to create cartoons, animations, and even the simplest games, informative models of natural processes. And it is already one direction of the basis for STE(A)M-approach studies.

Demonstrating the approach is relevant to a teaching approach in general programming courses for the first-year non-IT students at Tallinn University of Technology, Estonia. The authors suggest ways to achieve better results in programming issues that are usually complicated for beginners [17, 18]. The main aim of the chosen teaching approach in the course is to raise motivation and keep the learners’ interest in the programming field at a high level.

We will note that visual programming environments are the most acceptable for the development of electronic informational models. Automatic educational systems based on multimedia technologies are the perfect means of study. The combined use of computer graphics, animation, video, sound, and other multimedia components all gives unique possibilities to do an object that is studied, maximally evident, and that is why clear and accessible [19].

STE(A)M approach in the organization of educational activity gives an opportunity uniquely to connect technologies, science, and work. Facilities of Scratch projects can bring all of them up.

3.2. Development of the distancing course “Creative self-realization in Scratch”

As we mentioned, Scratch was an effective tool for students of different ages. Therefore, this environment is especially effective for future teachers – students of a pedagogical institution of higher learning. Here is, for example, devised the course [20].

The distance course consists of a few blocks. Employments provide for demonstrating and studying theoretical material, creating the project in the Scratch environment, mastery, and evaluation using test tasks.

This course introduces you to programming for beginners with one of the simplest programming languages. Mastering it, everybody can create computer programs and connect the graphic blocks of code, for example, to create animation, games, and the construction of interactive histories. The task of the course is to compel students to think like programmers and software engineers. A critical moment of this course is the development of creative projects.

The basic components, of course, are:

- developments of lectures. Lecture topics were determined by the research described below (figure 1);
- video lessons. The material is designed as an instruction for working in the environment (figure 2);
- tests. The construction of most questions consists in choosing one or more answer options (figure 3);
- projects. The created projects concern the study of mathematics, physics, and art (figure 4);
- interactive. Interactive tasks for mastering the material are here (figure 5).

Your first computer program

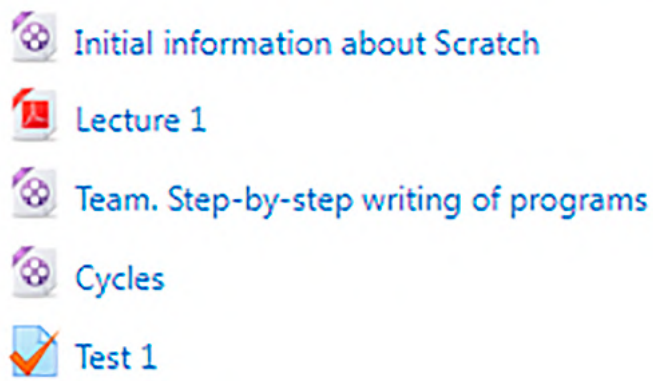
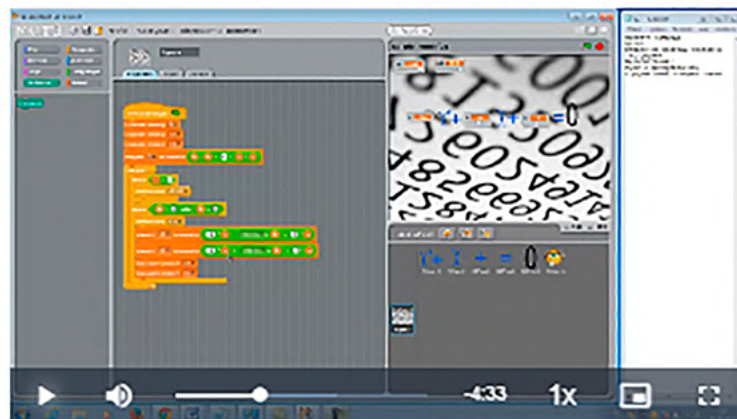


Figure 1. An example of Moodle educational resources for studying a separate module.

Team. Step-by-step writing of programs



← Lecture 1

Cycles →

Figure 2. Demonstration of the video lesson in the player window.

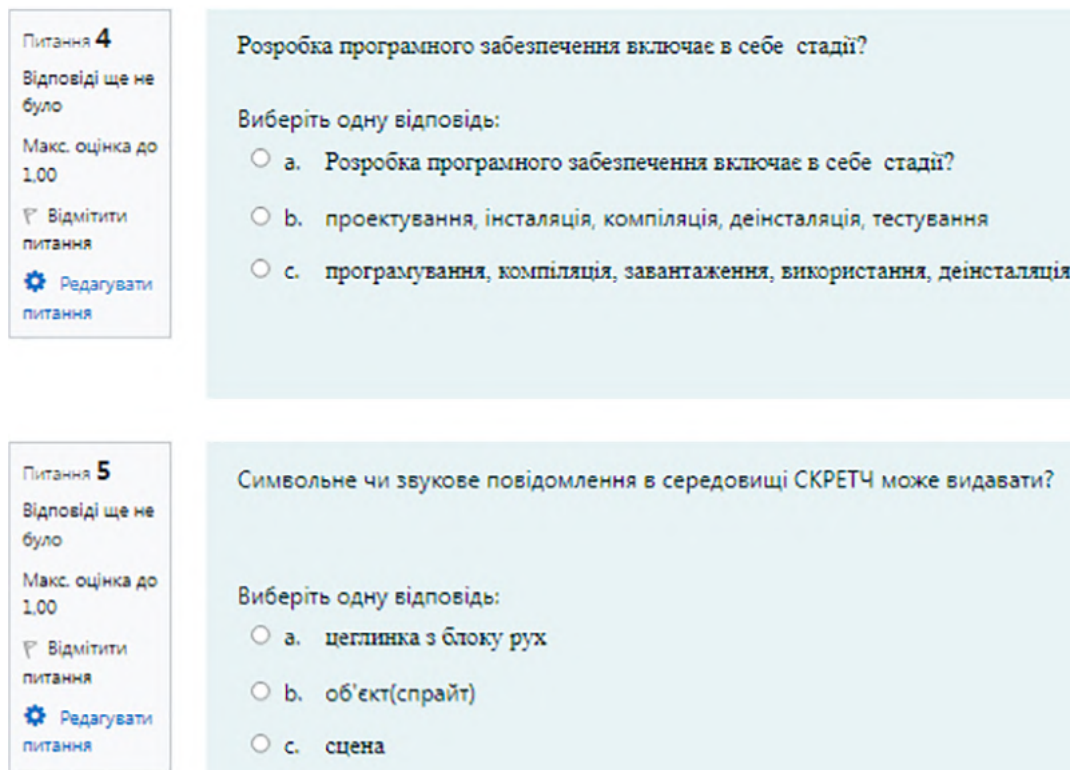


Figure 3. Control questions for choosing one correct answer to Ukrainian-language tasks.

3.3. Scratch-projects for the study of mathematics, physics, and art

The aims and maintenance of teaching informatics have considerably changed over time: from a variant course to invariant, from propaedeutic to base, and from an acquaintance of ICT to the formation of base knowledge and abilities. Capturing algorithmic thinking takes time and effort. For this purpose, it is necessary to prematurely learn to forecast the situations that can happen in the future and envisage in plans correct behavior in these situations. On the other hand, as well as other human skills, algorithmic thinking can be developed and trained through the purposefully neat system of exercises and carefully thought-out set of educational projects.

3.3.1. Scratch-projects in mathematics

1. The formula for finding the roots of a quadratic equation.

The aims of the project are:

- to obtain mastering of maintenance of concept “discriminant of the quadratic equation”, the formula of discriminant and chart of the display of formulas for solving of quadratic equations of general view, and also formulas of roots of quadratic equations;
- to form primary abilities to find the discriminant of the quadratic equation after formulas, after his value determines the number of decisions of affected quadratic and calculate the roots of affected quadratic.

Scratch projects can be applied for clearness for a teacher or as a result of mastering program material students in their implementation.

This project is clarity or a simple toy that explores the existence of roots in a quadratic equation. The principle is quite simple. Use a discriminant! And the hero of the “Clever Smile” talks: “roots exist” or “roots don’t exist” (figure 6).

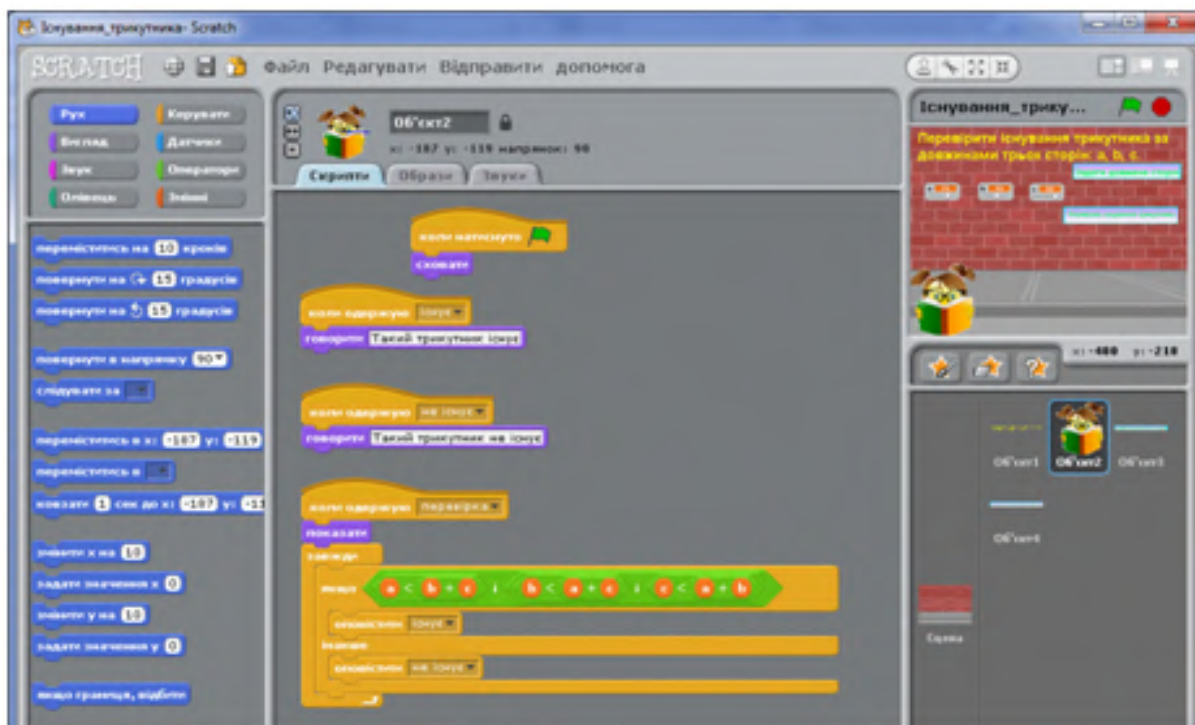


Figure 4. An example of the project implementation algorithm in the Scratch environment.

Code reuse




-  Tasks for own projects
-  Solve problems with a list (array)
-  Project Dance

Figure 5. Some interactive tasks.

A course for comparison of the task is done in the programming of Pascal language, too.

2. The next mathematical project is “Similarity of triangles”. Here are used the operators of branching: “If-Then-Else” and the simple operating under the inequalities (figure 7). A project determines the necessary and sufficient condition for the existence of a triangle after the check of the lengths of three sides of the triangle. Here is executed the inequality of the triangle. The object of implementation is a girl who helps you decide on the task. The user only enters the lengths of the sides of the triangle. Finally, the put algorithm of actions is implemented to calculate inequalities (figure 7). The use of similar auxiliary facilities of such type in mathematics lessons is necessary because it is an effective means of activating and supporting educational-cognitive activity. In this case, exactly, an educational process tests quality changes, becomes considerably more attractive, and, for students and teachers, pleases them from communication, labor, and

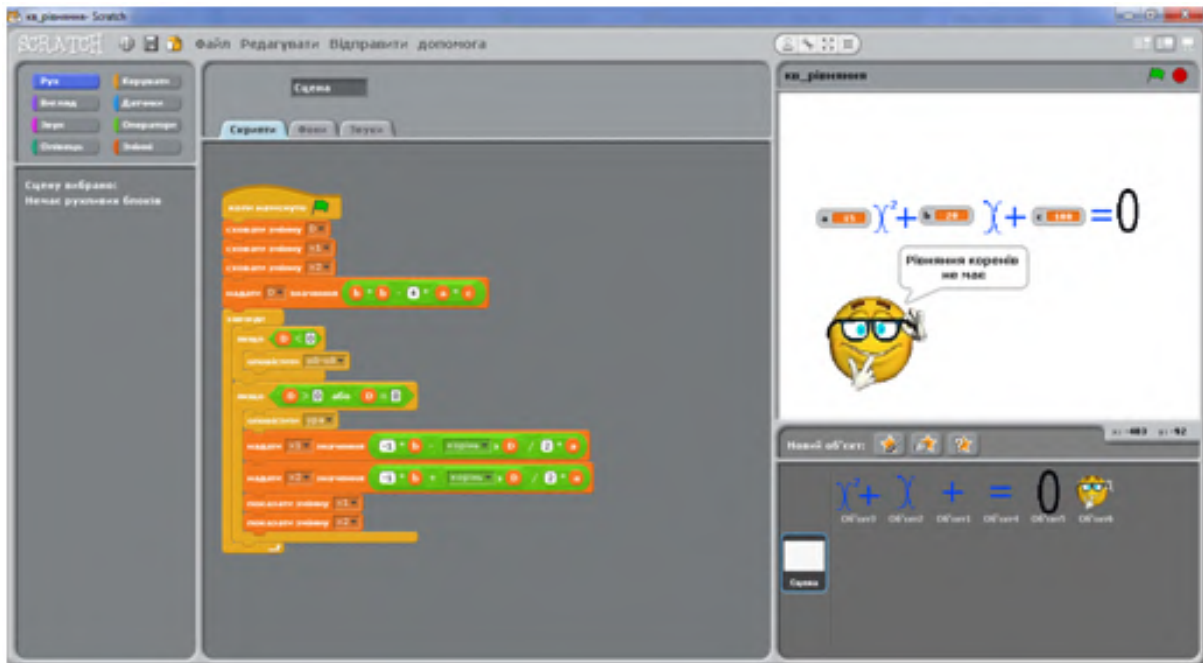


Figure 6. Algebraic project on finding roots of the quadratic equation.

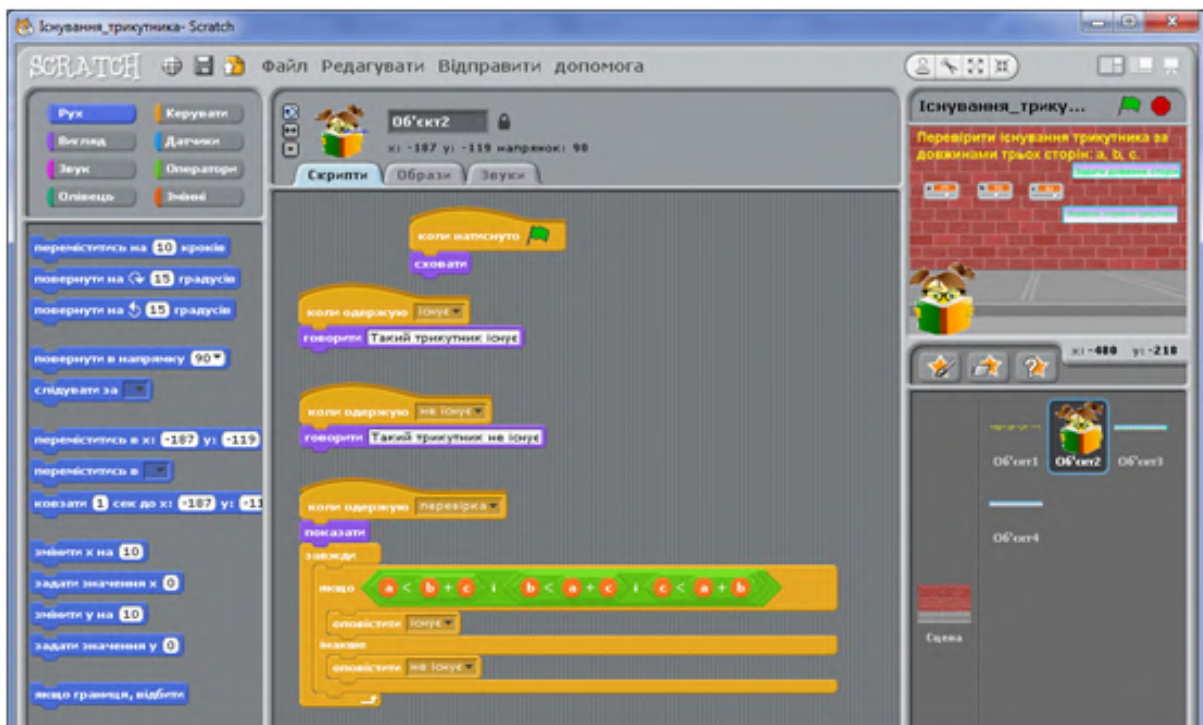


Figure 7. Using branched structures to check triangle inequalities.

purchasing knowledge. The use of Scratch brings in studies fundamentally new cognitive facilities. It assists a transition from the explanatory-concordance type of educational process to new and active ones that the use of various kinds promotes.

3.3.2. *Scratch-projects from physics.* Scratch assists in creating a variety of subject activities for students, allows the development of the child’s personality, and promotes motivation to receive quality education. The use of such projects in the study of physics allows for designing and demonstrating processes inaccessible for supervision in the conditions of the class of physics.

Scratch projects as auxiliary facilities in the study of physics also serve evidently as an explanation of new material and as a research laboratory that will execute the same work only in virtuality but will be reasonable and confirmed by the previous laboratory.

1. Determination of equalization of thermal balance.

The task of this project is to check the correctness of the experiment, draw up the heat balance equation, and determine the temperature of the resulting mixture. Figure 8 shows the use of value assignment operands in the Scratch environment to solve this problem. Its result will determine the efficiency of the heater. As you can see in figure 9, we use a timer to simulate a natural process in this project.

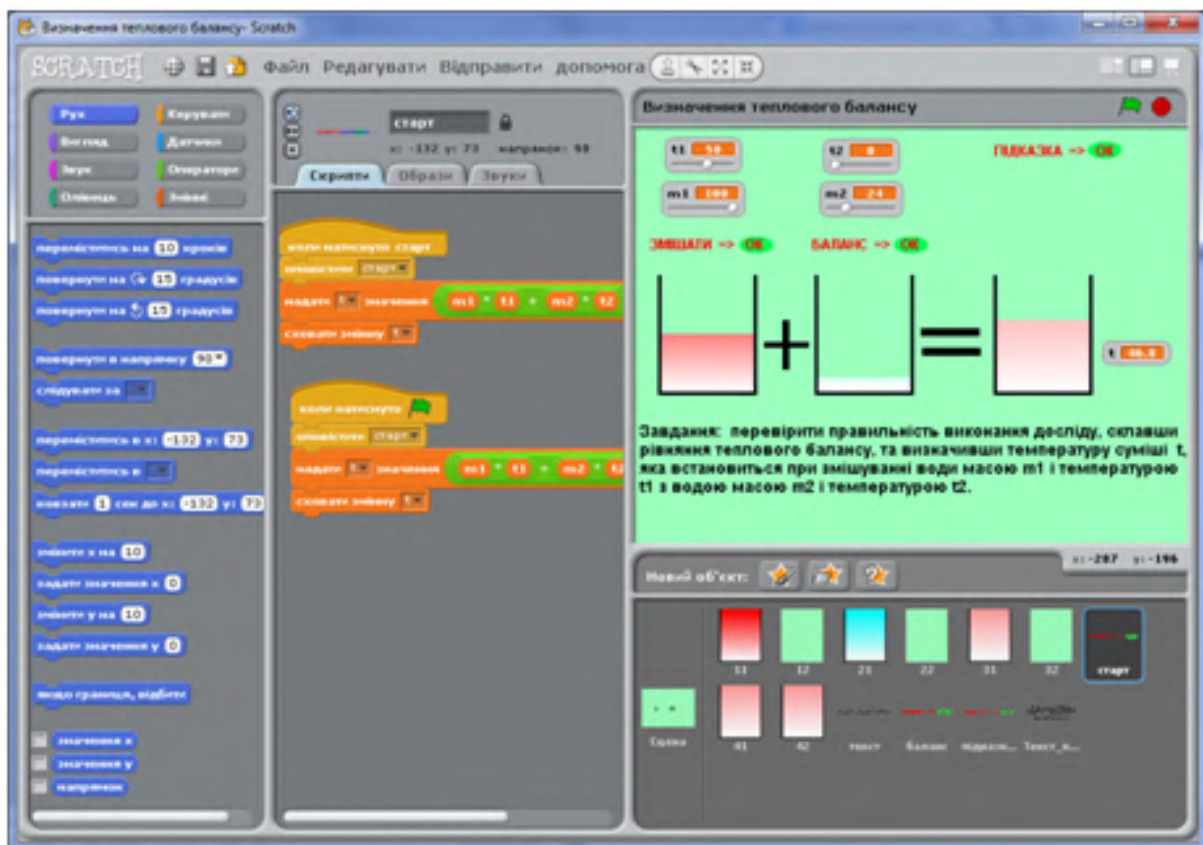


Figure 8. Using assignment operands to determine the temperature when mixing two liquids with different temperatures.

2. The motion of the body horizontally hurled.

The free-falling direction of gravity coincides with the direction of speed. A body moves rectilinearly and uniformly accelerated. As a result of adding these motions, get a curvilinear speed-up motion (a trajectory is a parabola). Such tasks can easily be realized in Scratch (figure 10). Moreover, an unambiguous concept decision does not eliminate the different creative approaches of the project.

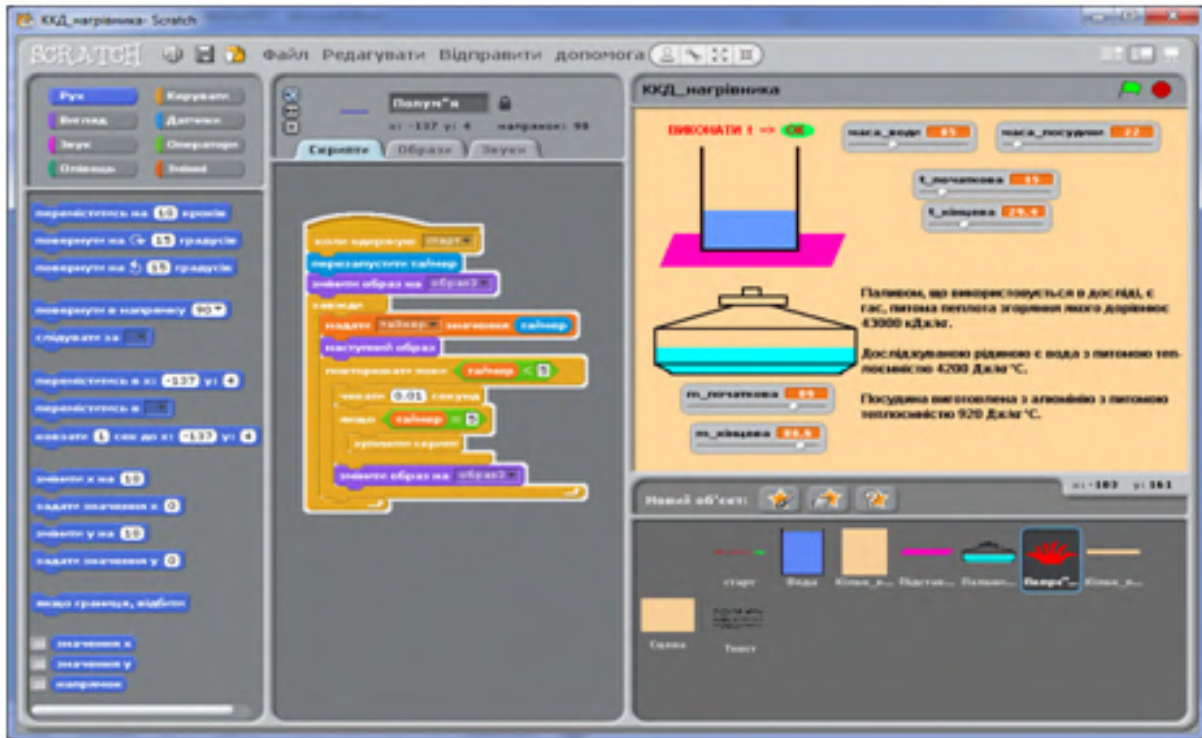


Figure 9. The use of timers in the algorithm for determining the efficiency of the heater.

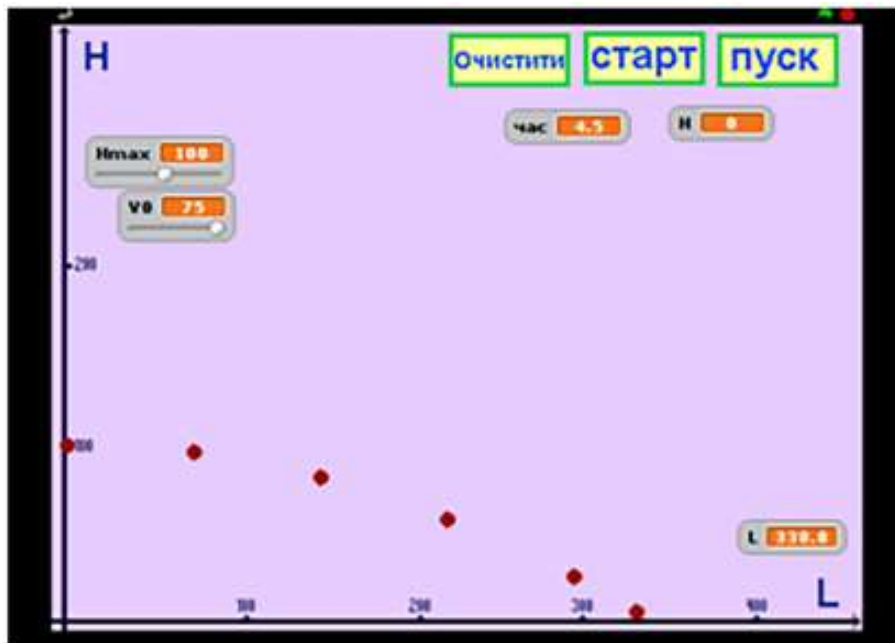


Figure 10. Construction of the trajectory of the movement in the Scratch project according to several parameters.

3.3.3. *Artistic projects of Scratch.* Using digital instruments to create and process multimedia data translates the study of artistic disciplines to a new level. Among directions of organization

of educational activity: music (forming of record library, editing of sound), perception, song work (karaoke, creation of phonogram, adjusting of speed and key of songs), and video editing (video clips).

- Virtual tuner

The project aims to work out a tuner that will help with the guitar’s tuning. Realization of the project does not require material charges.

Thus, a project shows the programmatic version of an electronic tuner for tuning six guitar strings in the key (E4, H3, G3, D3, A2, E2) (see Figure 11 in Ukrainian). The program is simple, and the principle of its work is like an ordinary tuner. Every note has an identical code: an instrument is set by the number 26 (a guitar with steel strings), and the number 64 sets the numerical order of notes. 3-times means that a note unit 3 sounds, then 1 unit is a break, and 3 units sound farther.

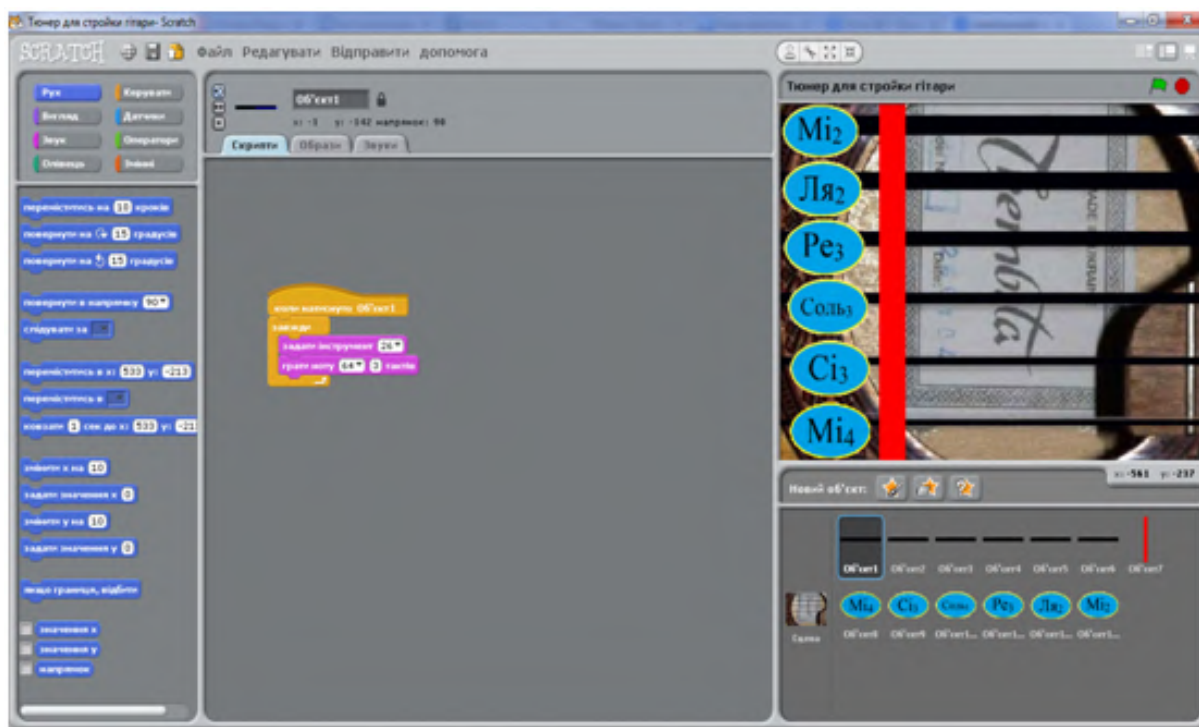


Figure 11. Setting up a virtual tuner.

4. Experimental research

The main goal of our experimental research was to clarify the maintenance of the course “Creative self-realization in Scratch” in terms of the credit-module system in the searching stage of the experiment. To achieve this aim, we used expert estimations.

All the fundamental questions of the questionnaire of the mentioned course were numbered after the increase of signs. Experts were selected from the teachers of informatics of the city Ternopil and Ternopil region. Then we offered them to specify the place of semantic themes, which are the most necessary for the study of programming and mastering the Scratch technology. The value of “1” was assigned as the most crucial topic in the opinion of the expert, and “10” is the least important.

The results of experiment for “Creative self-realization in Scratch” were implemented in course for students: “Computer information technologies in education and science”.

To avoid the psychological prompt that could influence a choice of the expert of a certain sequence of ranking, the offered themes in every card with questionnaire (table 1) were numbered in a randomized sequence.

Table 1. A card of questionnaire with the list of themes.

No	Theme	Place
1.	Basic constructions of programming: following, branching, cycle	
2.	General development of projects is in the programming of the Scratch environment	
3.	Use of Control unit in the environment of Scratch as libraries of basic commands	
4.	Documentation, instructions, and testing of own programmatic products	
5.	Work with operators with the basis of mathematical thinking in programming	
6.	Searching optimization of projects	
7.	Bases of development of projects in the industry of programming as a help to other areas of science	
8.	Use of variables, subroutines	
9.	Technologies of development of auxiliary program are in life	
10.	Facilities for testing of scripts of programs	

The results of the expert survey are presented in table 2.

The most obvious indicator of the evaluation of a theme is its total rank, which all experts determine [21]

$$S_j = \sum_{i=1}^{20} R_{i,j}, \tag{1}$$

where $R_{i,j}$ is the indicator set by the i -th expert, $0 \leq i \leq 20$, for the j -th theme, $1 \leq j \leq 10$.

However, such aggregate ranks are objective if there is some level of agreement between experts. The degree of such agreement is described by the concordance coefficient W . For each theme, we find the difference between the total indicators $\sum_{j=1}^m R_{i,j}$ and value $\frac{m \cdot (n+1)}{2}$:

$$d_j = \sum_{i=1}^{20} R_{i,j} - 0.5 \cdot (m \cdot (n + 1)),$$

where m is the quantity of experts, $1 \leq i \leq 20$, $m = 20$ and n is the quantity of theme and $1 \leq j \leq 10$, $n = 10$.

We find the sum of the squares of the values obtained from the equation (1)

$$S(d^2) = \sum_{i=1}^n d_j^2 = \sum_{j=1}^n \left(\sum_{i=1}^m R_{i,j} - 0,5 \cdot (m \cdot (n + 1)) \right)^2 \tag{2}$$

The maximum value of the quantity $S(d^2)$

$$S_{max}(d^2) = \frac{1}{12} \cdot m^2(n^3 - -n)$$

Table 2. Survey results.

Expert	T 1	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9	T 10
1	5	4	8	2	3	7	9	1	6	10
2	4	3	6	1	5	8	10	7	2	9
3	2	4	10	3	1	8	9	6	7	5
4	3	5	7	1	4	9	8	2	10	6
5	1	5	7	2	3	10	8	6	4	9
6	4	7	5	6	2	8	9	1	3	10
7	1	5	8	3	6	10	9	7	2	4
8	5	6	8	7	1	9	10	3	2	4
9	2	3	9	4	1	6	10	5	7	8
10	4	6	7	3	2	8	9	1	5	10
11	3	7	6	2	4	8	10	5	9	1
12	3	6	8	4	5	7	10	2	1	9
13	1	5	6	2	7	8	10	3	4	9
14	6	3	7	1	5	9	8	2	4	10
15	5	4	10	3	8	7	9	2	1	6
26	1	2	7	5	3	6	10	8	4	9
17	2	1	8	4	5	9	10	3	6	7
18	4	8	6	1	7	10	9	3	2	5
19	2	7	10	3	4	6	9	5	1	8
20	1	3	8	4	7	10	9	2	5	6

Table 3. Rating results.

	T 1	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9	T 10
S_j	59	94	151	61	83	163	185	74	85	145
d_j	-51	-16	41	-49	-27	53	75	-36	-25	35

is achieved if all experts evaluate the criteria (themes) equally.

The concordance coefficient is equal to:

$$W = \frac{S(d^2)}{S_{max}(d^2)} = \frac{12 \cdot S(d^2)}{m^2(n^3 - n)} \tag{3}$$

We find the values of the total ranks and d_j , $1 \leq j \leq 10$ (table 3):

From equations (2) and (3) we find the coefficient of the concordance of $W = 0,583$. This size always is between 0 and 1. If $W = 0$, then connections between the ranking of experts do not exist. Next, if $W = 1$, then connections between the ranking become completely gathered. The obtained here coefficient W is equal to 0,583, which substantially differs from zero. So, it is possible to assert that an objective concordance exists between the experts. However, this value of the coefficient W is not a criterion of objectivity since it can be obtained as a result of randomly assigning ranks to one or another topic.

The value $m \cdot (n - 1) \cdot W$ is distributed according to the χ^2 law with $n - 1$ degrees of freedom. Using the relation

$$\chi^2_W = \frac{12 \cdot S(d^2)}{m \cdot n \cdot (n + 1)},$$

we find the value $\chi_W^2 = 104,99$. If we compare this with the value from Table 3 for $i = n - 1 = 9$ degrees of freedom and a significance level equal of 0.05, we get $\chi_W^2 = 104,99 > \chi_t^2 = 16,92$, from which we conclude that there is agreement between the experts.

Due to the results of the questionnaire, the most essential themes for holding a special course are the following:

1. Basic constructions of programming: following, branching, cycle;
2. Documentation, instructions, and testing of own programmatic products;
3. Use of variables, subroutines.

Another way of using Scratch technology is to present novel conceptions. There was performed a questionnaire with the following points of view:

1. What communication technologies can be used for visualization and demonstration of various things, working results, investigations, and project performances?
2. What basic descriptions can technology own for the best presentation of ideas/results, etc.?
3. Are you familiar with the Scratch environment?
4. How can you apply Scratch-project for the realization of ideas?
5. How do the performances of speakers who used projects in the presentation of Scratch-, differ?
6. Do you see the advantages in applying Scratch projects for your presentation?
7. What kind of disadvantages in applying Scratch-projects do you see?

It is worth noting that we surveyed the prism of STE(A)M education. The results showed that the Scratch technology can be one of the basic ones in this direction. First, the implementation of projects in the natural sciences looks very obvious. Second, mastering Scratch as a technology allows students to learn basic algorithmic constructions. Thirdly, the use of various blocks and their creative combination promotes the development of technical creativity. Fourth, working with media data makes it possible to create interesting artistic projects. Fifth, mastering algorithmic structures is impossible without understanding the mathematical apparatus.

Among the characteristics necessary for the best presentation of their ideas, respondents singled out the possibility of a non-standard approach and creative implementation. Developing projects in Scratch is a great way to demonstrate your own solutions.

As part of the training “Digital technologies in education and science” for a group of master’s students of Ternopil National Pedagogical University named after Volodymyr Hnatyuk, students were enrolled in the course “Creative self-realization in Scratch” and invited to develop their projects using Scratch. All educational materials for acquiring labor skills under this program were available during the course. Video lessons made it possible to get to know the unknown and test the possibilities of technology at a time convenient for master’s students. The topics of the projects covered physical and mathematical, natural, artistic, and philological disciplines. Performances in which speakers used this digital technology looked qualitatively at the highest level. Master’s students noted new opportunities for the implementation of their projects.

5. Conclusions

The need for digital competencies is acute today. Their development is influenced by a number of factors, in particular, the improvement of the content of higher education. One of the ways to improve is to create courses that are of interest to students. The developed educational course “Creative self-realization in Scratch” implements the STE(A)M-approach in the organization of educational and cognitive activities of students of Ternopil National Pedagogical University named after Volodymyr Hnatyuk University. The content of the course was selected through

an experimental study. It is hosted on the Moodle platform used at the Volodymyr Hnatiuk National Pedagogical University in Ternopil. Its components include lecture materials, video lessons, tests, etc. The emphasis is on project activities. It is advisable to master the Scratch technology by implementing creative projects in mathematics, physics, music, etc. These disciplines perfectly combine technology and creativity. It has been established that using Scratch technology allows us to express our thoughts and ideas non-standardly. The development of interactive interaction interests the listeners and activates the perception of the outlined question. In addition, there is a study of technologies and the formation of an algorithmic thinking style. In such a way, digital skills are formed. Introducing such courses into the educational process confirms the STE(A)M approach to education.

In the future, it is planned to expand the scope of Scratch projects.

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Experience of interdisciplinary projects implementation in the training of pre-serviced IT-specialists

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Abstract. The problems of contemporary IT specialists' training in terms of the high requirements to their mathematical and computational thinking skills as well as the urgency of raising their motivation to mastering math and algorithmization are discussed in the paper. It is pointed out that initial university courses should involve the students in the experiences that focus pre-service IT-specialists on the deep understanding of a mathematical background and an algorithmic nature of any coding task, demonstrate them the role of math in the analysis of algorithm characteristics, and importance of math knowledge in for successful IT-career. One of such experiences presented by the authors is involving the pre-service IT-specialists into the work upon the interdisciplinary projects. The said activity is elaborated basing on the core didactic principles of PBL with the focus on the interdisciplinary project peculiarities. The goal, stages and results of the said PBL are described and analyzed in terms of its impact on the students' awareness of mathematical knowledge value in their vocational activity. The levels of formation of the IT-specialists' awareness of mathematical knowledge value are established and determined. The survey and monitoring program were developed and realized which showed the changes in the distribution of pre-service IT-specialists by the levels of the said awareness for their future IT career. The prospects of further research are outlined in terms of holding the empirical research for the verification of the offered PBL activity impact on the motivation to IT-specialists' learning math. The software module's core components are distinguished and the set of requirements in terms of their design are formulated according to the logic of the components work.

1. Introduction

The urgency of this research stems from the rapid growth of IT industries and the evolving nature of their challenges. As tasks in these fields become more sophisticated and mathematically intensive, there is an increasing demand for highly skilled professionals. This necessitates a renewal of approaches to computer science education to equip future IT specialists with the ability to create quality software and develop mathematical and computational thinking skills [1].

Contemporary paradigms in global IT education [2–4] recognize computing as a family of interconnected domains, encompassing both fundamental and applied knowledge areas. The



ongoing evolution of these fields has led to the emergence of new areas at the intersection of mathematics, applied sciences, and traditional computer disciplines. Consequently, modern computer science education faces the challenge of cultivating mathematical and computational thinking skills in IT specialists [4–8]. These skills are crucial for comprehending diverse real-life problems, formalizing them mathematically, and devising efficient solutions that are intelligible to both humans and machines.

However, current educational practices and recent studies reveal a concerning trend: many students pursuing IT specializations demonstrate low awareness of the value of mathematical knowledge for their professional development. This results in diminished motivation to study mathematics and acquire mathematical thinking skills [7, 9–11]. To address this issue, introductory university courses should engage students in experiences that emphasize the mathematical foundations and algorithmic nature of coding tasks. These courses should also illustrate the role of mathematics in analyzing algorithm characteristics and highlight its importance in the modern IT industry.

One effective approach to achieve these goals is to involve pre-service IT specialists in interdisciplinary projects. Such projects can help students recognize the integrative nature of real-world problems, which often require knowledge and skills from various intersecting subject domains. Simultaneously, these projects can demonstrate the high value of mathematical knowledge and thinking in solving complex, multifaceted challenges in the IT field.

2. Purpose of the work

In light of the factors emphasized above, the purpose of this paper is twofold:

- (i) To elucidate the distinctive characteristics of interdisciplinary project-based learning in the context of IT education.
- (ii) To investigate the benefits of this educational approach for pre-service IT specialists, particularly in terms of enhancing their awareness of the value of mathematical knowledge in their future professional activities.

3. Theoretical framework

This research is grounded in the didactic principles of project-based learning (PBL) within the context of vocational training. Additionally, it incorporates theoretical foundations of pedagogical diagnostics to assess students' awareness of mathematical knowledge value and its evolution through interdisciplinary project-based learning.

Project-based learning, as defined in pedagogical literature [12–14], is a didactic strategy that enables students to acquire theoretical knowledge and practical skills through engagement with projects centered on real-world problems they may encounter in their future careers.

PBL is characterized as a teaching method where trainees actively participate in practically, socially, or personally significant projects to deeply master educational content. It involves students in investigations to answer complex questions or solve challenging real-world tasks. This approach encourages the application of in-depth content knowledge, higher-order thinking abilities, creativity, and collaboration skills. Moreover, PBL tends to generate collective creative energy among students and teachers, which is particularly valuable in the context of online learning. Consequently, PBL renders training more engaging, humanistic, and practically relevant for students [11, 13, 15].

Implementing high-quality PBL requires specific efforts from educators and adherence to certain didactic principles. Recent studies have formulated guidelines with core rules for project task formation and implementation. These guidelines encompass crucial project design elements that form the basis for high-quality projects and project-based teaching practices.

According to studies [11, 14], the project design elements include the following recommendations:

1. Projects should have real-world context or appeal to students' personal interests.
2. Projects should be framed by a significant problem or complex question requiring appropriate tools and quality standards for resolution.
3. Projects must involve investigation, engaging students in formulating questions, searching information resources, and testing hypotheses.
4. Students' opinions should be considered, allowing them to make decisions and express their thoughts.
5. Students and teachers should reflect on the effectiveness of their research and project activities, the quality of project work, and strategies for overcoming obstacles.
6. Projects must result in a public product that students share beyond the classroom.
7. Work revision is expected, with students receiving and utilizing feedback to refine their product.

Furthermore, guidelines for educators to ensure PBL efficiency have been established [7,11]. These include:

- Clearly formulating project tasks and aligning them with course objectives.
- Planning implementation from start to finish, considering students' choices and perspectives.
- Ensuring projects address key competencies from relevant subject domains.
- Promoting student progress, independence, inquiry, quality focus, and team spirit.
- Managing student activities and supporting task assignment, scheduling, and resource utilization.
- Employing diverse instructional strategies to engage all students in achieving project goals.
- Participating in product development alongside students and determining when knowledge extension, skill-building, encouragement, or assessment is needed.
- Using formative and summative assessments to evaluate demonstrated knowledge, abilities, and skills in both team and individual work.

In the context of this research, special emphasis is placed on the characteristics of interdisciplinary project-based learning. PBL can have an interdisciplinary nature by connecting various subject domains and skills to the project theme and its outcomes. For instance, in IT specialist training, students might engage in designing a smart city model incorporating mathematics, science, engineering, art, and social studies. Such interdisciplinary projects possess unique features and require special preparation at all stages of PBL implementation [6, 13, 14].

Thus, at the stage of the project task formulation and project design, it should be regarded that interdisciplinary project involves the combination of multiple academic disciplines and draws knowledge from several subject domains both included into the students' curriculum and other areas directly or indirectly linked with them. So, the project task must include real-life complex problem provoking students' thinking across boundaries and applying also cross-discipline methods and research tools.

In the progress of work upon the project, recommendations as for the teacher's activity and mission should be enriched with additional requirements. Unlike pure disciplinary projects which typically involve analysis, research, and problem-solving within the boundaries of the exact discipline, interdisciplinary projects must expect integration of knowledge and methods from multiple disciplines which encourage students to do interdisciplinary investigations that

lead to creation of the product absorbing the achievements of various subject domains. It should be emphasized and encouraged by the teachers in the progress of students' work at all the stages.

It is also relevant to point out that implementation of PBL focused on the interdisciplinary projects design introduces into practice the strategies of STEAM education that integrates science, technology, engineering, arts, and math (STEAM) in a holistic and creative way [16]. Work upon such projects is able to promote students' interdisciplinary thinking by encouraging them to explore the links and intersections between different knowledge fields [17]. Among the examples of similar projects for pre-service IT-specialists the practitioners present, for instance, projects where students are encouraged to use coding, robotics, and music to create interactive musical instruments based on scientific concepts and harmonic principles; or it is expected to apply geometry, art, and computer science to design and generate origami patterns.

The depicted guidelines were used to organize, encourage and manage the students' work upon the interdisciplinary projects within several courses for IT-specialists' training.

According to the purpose of our work, we are going to investigate the benefits of interdisciplinary projects-based learning for the pre-service IT-specialists in terms of their awareness of mathematical knowledge value in their professional activity. Thus, in terms of our research there were used some theoretical basics of pedagogical diagnostics of the said parameter and its changes in the progress of the interdisciplinary projects-based learning.

In particular, there were established three levels of formation of the IT-specialists' awareness of mathematical knowledge value (here and below – Parameter): reproductive, productive, and creative levels. They can be determined in such a way.

The student reveals the Parameter on the reproductive level, if he underestimates the value of mathematical knowledge; believes that the professional tasks in IT-sphere can be successfully solved without deep understanding of math; manifests a situational (impersistent) desire to get acquainted with the latest achievements in math and implement them in future professional activity.

The student reveals the Parameter on the productive level, if he recognizes the value of mathematical knowledge; believes that the efficient professional tasks solving in IT-sphere requires deep understanding of math; periodically gets acquainted with the latest achievements in the field of mathematics and recognizes the needs to implement them in future professional activity.

Finally, the student reveals the Parameter on the creative level, if he deep beliefs as for the value of mathematical knowledge; understands that the efficient professional tasks solving in IT-sphere is impossible without high-level math knowledge; is interested at the latest achievements in the field of mathematics on the permanent basis and is ready to implement them in future professional activity in creative way.

In addition, based on some sources analysis [5, 10, 18, 19], there were revealed some diagnostics instruments to measure the students' level of the Parameter formation: survey and monitoring. There were elaborated the questionnaire for the survey and the monitoring program.

4. Results and discussion

Based on the presented theoretical framework, there was arranged, encouraged and managed the students' work upon the interdisciplinary projects within several courses for IT-specialists' training on purpose of raising students' awareness of mathematical knowledge value and readiness of their implementation in future professional activity.

Highlighting the experience of the PBL focused on the interdisciplinary projects in the progress of pre-service IT-specialists' training, it would be mentioned that there were offered different interdisciplinary problems like (1) gamified product "Computer simulator of the

tournament between the different game algorithms”; (2) simulator “Tessellations in art”; (3) navigator in university campus and others.

However, we would like to cover in detail the project integrating main concepts of math, algorithmization, programming, ethnography and art of national embroidery. In particular, at the initial courses of their vocational training, pre-service IT-specialists were offered interdisciplinary research project “Ukrainian embroidery”.

The goal of this interdisciplinary project is to investigate design and regularities of Ukrainian embroidery as a result of geometrical transformations, and develop a software generator of embroidery patterns. The work upon the project was arranged according to the educator’s guidelines of PBL focused on interdisciplinary projects development.

At the planning phase of the project, the exact tasks were formulated clearly and adapted by the teachers to the core goals of IT-specialists’ training addressing the key competences from the subject domains involved.

It was planned the project implementation from start to finish, taking into account trainees’ choices and minds. Thus, at the first stage of work, according to the project peculiarities, the students had to delve into the history of Ukrainian traditions, their cultural significance, national self-identity, adaptation of the folk creativity to the modern terms. Within this stage of the project, students implemented ethnographic zoning of Ukraine carried out according to local differences between specific performance techniques of embroidery, typical ornamental motifs and compositions, a common color scheme etc. There were distinguished embroidery, typical for the Dnieper region, Polissia, Podillia, the South, the Carpathians, etc.

At the next stage of the project work the students were encouraged to investigate the geometrical basics of the embroidery design using GeoGebra software of dynamic math [17]. Here the students manipulating GeoGebra facilities found out that the ornament consists of sub-ornaments divided into rapports, which in turn, is divided into smaller particles – motifs or minimal patterns. So, a rapport is built of the motifs which undergone the geometrical transformations of different types: reflection (mirror symmetry, symmetry), rotation, parallel transfer (translation), sliding reflection.

After the investigation stage there was the design stage, when the students had to use the results of their geometrical embroidery investigations in order to create the tool kit in GeoGebra, which allowed to implement the basic elements of an embroidery ornament (figure 1) and build more complicated ornaments. At this stage the students had to master and apply such GeoGebra components as Geometry and Sequence for iterative constructions.

The results of these geometrical investigations and design steps in GeoGebra environment made a basis for the following up development of a software generator of Ukrainian embroidery in Python programming language. The developed program – generator simulates the process of embroidery in different techniques, implementing different approaches to by-passing the embroidery pattern.

Thus, in addition to geometrical transformations, in the progress of the work upon interdisciplinary project, students had to master essential topics of computer science and discrete math in holistic and integrative way:

- turtle graphics and turtle library for simulating needle movements,
- lists and arrays to store embroidery schemes in .txt format,
- work with files,
- PIL library to work with images,
- graphs representation in Python language,
- depth search algorithm and others.

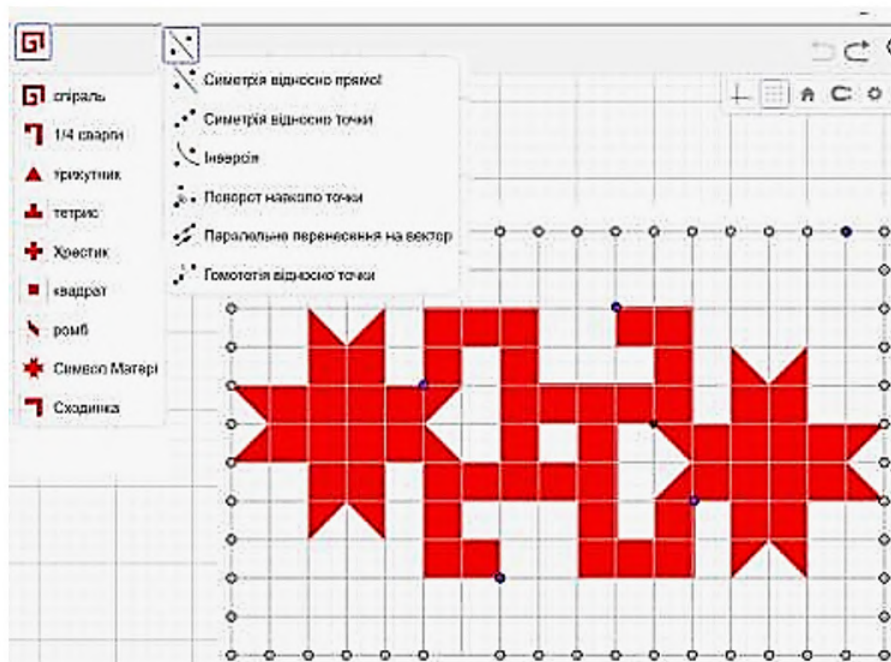


Figure 1. Built tool kit which allows implementation of embroidery ornaments.

Some episodes of work of the developed embroidery generator in the modes of building and editing embroidery schemes as well as a result of the built “embroidery” according to a scheme are presented in the figures 2, 3.

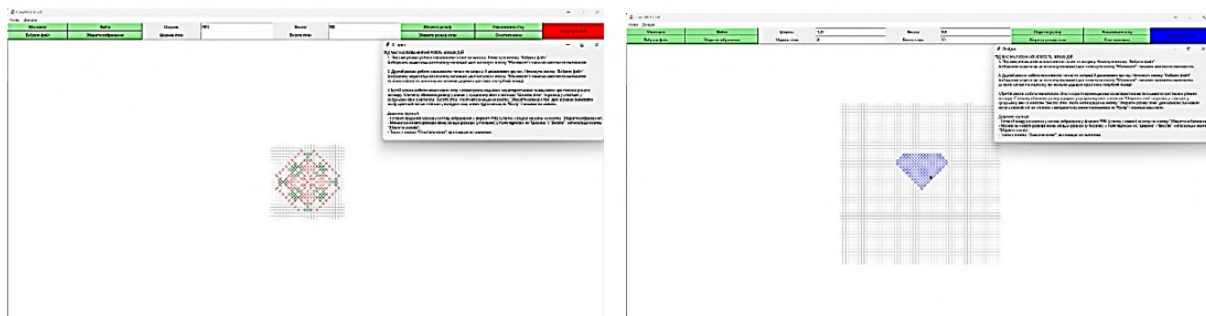


Figure 2. Episodes of work of the developed embroidery generator in the modes of building and editing embroidery schemes.

It is important to point out that at all the stages of work upon the interdisciplinary project, there were emphasized by the teachers the links between different sections of math and programming, between geometric investigations within GeoGebra dynamic software and their realization by their own program. It was also elicited from the students and summarized as a conclusion the value of math knowledge which in fact enabled realization of automatic embroidery and led to creation of the product absorbing the achievements of various subject domains (computer science, math, ethnography, and folk art).

It is intuitively clear that such an activity is really beneficial for the pre-service IT-specialists in terms of their awareness of mathematical knowledge value in their professional activity (Parameter). On purpose of understanding the impact of the said interdisciplinary projects-



Figure 3. A result of the built “embroidery” according to a scheme developed by the embroidery generator.

based learning on this Parameter there were prepared and conducted a survey and a monitoring program which allowed to reveal the changes in the levels of the students’ awareness of mathematical knowledge value.

Our monitoring, conducted according to the prepared program, indicated an increase in students’ motivation and a tendency to comprehend the mathematical foundations of the presented problems, as well as growing attention to algorithm construction. As anticipated, we observed an increased understanding of the role of mathematical thinking and algorithmic skills in the process of developing software embroidery generators.

Additionally, we conducted a survey aimed at revealing students’ hindsight and reflection on their work on interdisciplinary projects. The survey included a set of questions and tasks, such as:

1. How do you estimate your degree of mathematical knowledge application in the progress of developing the project product (according to the given scale)?
2. Has your perspective on the value of mathematics and algorithmic knowledge for coding changed? If so, in what way?
3. How do you estimate your level of comprehension of the mathematical originality of the given task (according to the given scale)?
4. What experience did you gain during the work on the project product?
5. How important do you consider this experience for your future IT career?

Summarizing the survey results, we can conclude the following:

- 75% of the trainees acknowledged that developing the interdisciplinary project encouraged them to apply mathematical knowledge more intensively.
- Over 60% of the students reported changes in their understanding of the practical value of fundamental mathematical knowledge for project product development.
- Approximately 80% of the participants admitted that such activity provided them with valuable experience in teamwork on mathematical analysis and investigations of real-life problems.

Furthermore, the survey revealed changes in the distribution of pre-service IT specialists across levels of awareness regarding the value of mathematical knowledge for their future IT careers:

- The number of students exhibiting a reproductive level of awareness decreased by 3%.
- The number of students demonstrating a productive level decreased by 5%.
- The number of students showing a creative level of awareness increased by 8%.

The results obtained from our monitoring and survey may serve as a foundation for conducting empirical research to verify the impact of the proposed PBL activity on IT specialists' motivation to learn mathematics, which constitutes a prospective direction for our future research.

5. Conclusion

This study addresses the challenges in contemporary IT specialist training, particularly the need to develop strong mathematical and computational thinking skills while increasing motivation for mastering mathematics and algorithmic concepts. We have demonstrated that involving pre-service IT specialists in interdisciplinary projects can be an effective approach to achieve these goals.

Our research highlights the importance of integrating mathematical foundations and algorithmic thinking into initial university courses. By engaging students in interdisciplinary projects, such as the "Ukrainian embroidery" software generator, we were able to demonstrate the practical application of mathematical knowledge in real-world IT tasks.

The implementation of project-based learning focused on interdisciplinary projects was guided by established didactic principles and tailored to the specific needs of IT education. This approach allowed students to explore connections between various disciplines, including mathematics, computer science, ethnography, and art.

Our findings, based on monitoring and survey results, indicate significant positive outcomes:

- 75% of students reported more intensive application of mathematical knowledge during project development.
- Over 60% acknowledged a change in their understanding of the practical value of fundamental mathematical knowledge.
- 80% recognized the value of teamwork experience in mathematical analysis and real-life problem-solving.

We observed a shift in the distribution of students across awareness levels regarding the value of mathematical knowledge for their future IT careers:

- A 3% decrease in students at the reproductive awareness level.
- A 5% decrease in students at the productive awareness level.
- An 8% increase in students at the creative awareness level.

These results suggest that interdisciplinary PBL can effectively enhance students' awareness of the importance of mathematical knowledge in IT and improve their motivation to learn mathematics.

Future research directions include conducting empirical studies to further verify the impact of this PBL approach on IT specialists' motivation to learn mathematics. Additionally, exploring the long-term effects of such interdisciplinary projects on students' career trajectories and professional success could provide valuable insights for curriculum development in IT education.

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Remotely controlled reality in the “Robotics Fundamentals” course for students of the “Information Systems and Technologies” speciality

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Remotely controlled reality in the “Robotics Fundamentals” course for students of the “Information Systems and Technologies” speciality

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Abstract. This paper presents the distance learning technology in the “Robotics Fundamentals” course for students of the “Information Systems and Technologies” speciality. The purpose of the educational process in this course is to form students’ understanding a robotics unit and its software as an information system. We need to stress the students’ attention on importance of feedback in such complex systems. The main idea of our approach is to show the students the real production process of robotics system creation as a sequence of steps from modelling and simulation in virtual environment to testing it the in the appropriate real environment. Choice of the software and hardware for supporting the distance learning process is discussed. We suggest some technical decisions according to the remote laboratory and students’ remote communications with the robotics system. Results of conducted surveys are analysed to evaluate the efficiency of study process in the course as well to distinguish tasks for future development od our learning technology.

1. Introduction

1.1. Statement of the problem

Robotics is one of the leading field of modern science and technology. The education in this field is provided from primary school to professional and university study. Of course, each level of education assumes some specific features in the style of teaching and accents in the learning material. The primary and secondary school uses robots as a kind of an agent that executes the algorithm and main purpose of this study is developing algorithmic thinking. Some gamification tool are used here to be controlled by pupils algorithms. The robotic toy with simplified system for programming or its virtual model are the best choice for educational process [1].

We need to form worldview and understanding of main principals of robotics in higher school and in teacher training educational institutions. We need to explain students the main idea of using sensors and feedback to control a robot (robotic system) performance and give a wide overview of using robotic systems. The key competencies in educational robotics were analysed in the overview of Morze and Strutynska [2]. They look on educational robotics as a part of STEAM education. The authors underline that educational robotics is a cross-disciplinary area



of students' learning and determine main content lines of educational robotics: basics of robotics; introduction to educational robotics (for teachers); programming of robotic systems; physical basics of robotics; mathematical basics of robotics; methods of teaching educational robotics (for teachers). Special tools on the base of microcontroller (for example, Arduino) with appropriate integrated development environment (IDE) that control the robot programming process is the best choice for learning activity on this level of education. For example, some robotics platforms and ready-made technical solutions for teaching pupils the robotics fundamentals are shown in the Baranov's overview [3]. On this level of education a student creates some simple deterministic algorithms. So it is possible to use some virtual model of a robot and appropriate software for virtual reality. Such a complex gives possibility to study robotics in distance learning educational process.

The main task of professional training and university education in IT specialities is to form competencies in constructing the robotic systems, developing appropriate software for real purpose under real conditions. Such training needs in real robotic system to be used in the educational process. We need to show real problems in developing software that deals with the some sensors errors, stochastic nature of an environment and limited accuracy of manipulator. Technical universities have appropriate equipment in their laboratories. But how to use it in distance learning? The virtual reality software does not give students possibility to detect and process some unobvious problems with robotic system control in real environments. But fixing this problems is the main competency of modern IT engineer. So we see the only way to organise the distant learning "Robotics" course – laboratory with the remote control. From the other hand we can use virtual laboratory for students' previous training before starting to work with a remotely controlled robotic system. We can find the such combination of learning methods in the works of researchers from Ternopil Volodymyr Hnatiuk National Pedagogical University. We can see the work of Mazur and Franko devoted to the Tinkercad virtual environment use in the training future engineer educators [4]. And we can see the work by Kozibroda et al. where remote accessed laboratory equipment are used [5]

1.2. Literature review

Modern trend of robotic system control in an environment with random obstacles is to use neural network. There are a lot of such studies, for example Statsenko et al. studied an autonomous mobile robot system that moved across unknown terrain utilizing the proposed decision-making model [6]. Such an approach is very important for robotic systems programming. But it does not show the mechanism of decision making. So, in our opinion, an learning process in robotic system programming should start with determinate logical mechanisms, such as productions.

Analysing structure of the remote learning system model for robot programming we can see the approach with using a computer that is placed in the laboratory and provide the communication with a robotic system (control, programming and video fixation). Student join to this computer via Internet and obtain the automated remote workplace [5]. Advantages of such an approach are in useful organising interface between a student and the robotic system, in using common tools for internet connection. Disadvantage, in our opinion, is in absence of direct student's operating with robotic system internal interface. A student work with some integral development environment instead of the real robotic system, so reality is not full.

Remote laboratory that was presented by Saravana Mohan et al. assumes to use IoT (Internet of Things) control [7]. This is a web-based remote access real-time laboratory for chemical experiments with real instruments such as Robotic arm, sensors, Cameras and other automatic devices. This system creates new opportunities for distance learning. Using Python as a programming language does the student work easy and scalable. This laboratory is also server-based: students operate with a server that operates with sensors and manipulators.

Kaarlela et al. suggested robotic teleoperation platform that allows teleoperation, remote

programming, and near real-time monitoring of controlled robots, robot time scheduling, and social interaction between users [8]. The authors care about cybersecurity of their platform and this is important issue in modern Internet. The authors underline the novelty of their platform in such features as social communication, resource sharing, content management, teleoperation, or support for mobile devices. This platform assume the robots to be attached to it. Using a digital twin allowing bi-directional data transmission from simulation models to physical robots and vice versa is the most interesting feature from our viewpoint. Combining virtual model with physical robotic system give us possibility to compare their performance and to see the model limitations. Also, the author prove that using the digital twin improve cybersecurity and safety for physical robotic system.

Su et al. speak about mixed reality for human-robot interaction [9]. Such an approach is very prospective for educational purpose, but it is costly enough. Such a laboratory needs to be equipped with special devices not only on the side of robotic system and server part, but also on the side of user. So, it is not possible to integrate virtual, mixed and augmented reality in the Ukrainian distance learning at present time. We can assume it for development “Robotics Fundamentals” course classroom study.

Important element of remote control is the communication between robotic system microcontroller and other devices. Such a task was solved by Kliuba and Likhouzova according to popular and wide available microcontrollers of the AVR family [10]. They study communication via Bluetooth and suggest a modified interaction protocol, an Arduino library that implements interaction on the microcontroller side, and a mobile application for user interface. This field of direct control the robotic system on the base of Arduino is interesting for distance learning, but we need to use Internet communication instead of Bluetooth.

1.3. Objectives

Development of the distance learning technology for robotics study is still topical. The key problems in this direction are the correspondence to the modern productive process in the field of robotics systems and its software development (from modelling and simulations to testing the system in the real environment) and using the learning research as an educational method.

The purpose of our study is to develop the distance learning technology in the “Robotics Fundamentals” course for students of the “Information Systems and Technologies” speciality and implement it into the educational process.

We continue our line in development of learning research method [11] and transform it for the robotics course.

2. Technologies and equipment

The educational process was organised as full distance learning and was supported with all traditional technologies such as learning management system, video-lectures and online consultations in Microsoft Teams. But the main component of learning tools is an online robotic laboratory that contains two separated parts: virtual software simulator of a robotic system and a laboratory with remote controlled physical robots.

The analysis of virtual software simulators (Lego mindstorm, Tinkercad, Gearsbot, VEXcode VR) led us for choosing GearsBot environment, because of such complex of advantages:

- GearsBot environment contains internal 3D-simulator that give students realistic picture of robot performance, this view is similar to the physical robot observation in our a laboratory;
- GearsBot environment suggests two modes of programming: using a constructor with visualised blocks of commands (Blockly) and using Python programming language; there are special tools for converting Blockly code into Python program code. The possibility

to use two programming modes and switch between them helps students complete tasks regardless of their programming language experience;

- GearsBot is a web application, it is executed in browser; this software is open source and cross platform, it is free of charge (GNU General Public License v3.0) [12]; so GearsBot environment is accessible for students on all devices with any operating system.

The main requirements for the laboratory with remote controlled physical robots are the such:

- low-level access to components;
- the system should be accessible at any variants of student's system customising and Internet provider requirements;
- student should be able to design such a robot by self with minimal costs;

We developed the structure of our system in accordance to these requirements. Let discuss our choice of hardware and software components in details.

To provide low-level access to the robot's internals, we need to use the microcontroller itself with appropriate tools to service it. Some constructors, such as Arduino (based on ATmega chips) and ESP-32 based boards, are good choices, taking into account our requirement for robot design by students. The costs of this tools are similar, but ESP-32 is more useful for our purpose: it contains built-in WiFi and Bluetooth modules, dual-core microprocessor and larger RAM. The key additional argument for our choice of ESP-32 was support of microPython programming language which provides an opportunity to control the microcontroller outputs without overwriting the firmware.

Combining all computers into one virtual network allows us to bypass the peculiarities of network settings from Internet providers and additionally get a protected confidential network. So the laboratory computer and students' computers should be joined to some global virtual network before starting the online laboratory work.

The general scheme of the working process organising in our laboratory with remote controlled physical robots is shown in the figure 1. The data transfer when a student work with a robot is shown in the figure 2.

So, the our system consists of such components:

- students' personal computers with installed Internet browser and VPN client;
- a university VPN server to create a safe virtual network;
- server (personal computer) in our laboratory (laboratory PC) that is plugged in to both the virtual network and the laboratory local network; the laboratory have not to be placed in the university building, it can be remote, and the laboratory computer can be connected to the university VPN server via Internet; the laboratory PC resents students' commands to robotics platforms without any transformation and provide students with the view from web-cameras in real time;
- wireless equipment to establish connection with robotics platforms in the local laboratory network;
- robotics platforms with microcontroller on the base of ESP-32 with built-in MicroPython software; the internal system of these robotics platforms must be customised to connect to the wireless network automatically, and the MicroPython Interactive Interpreter Mode (REPL) must be activated – to provide students with possibility to work with the microcontroller in the interactive mode by sending Python commands;
- web-cameras, which show the robots and there environment in real time for understanding there placement and operating.

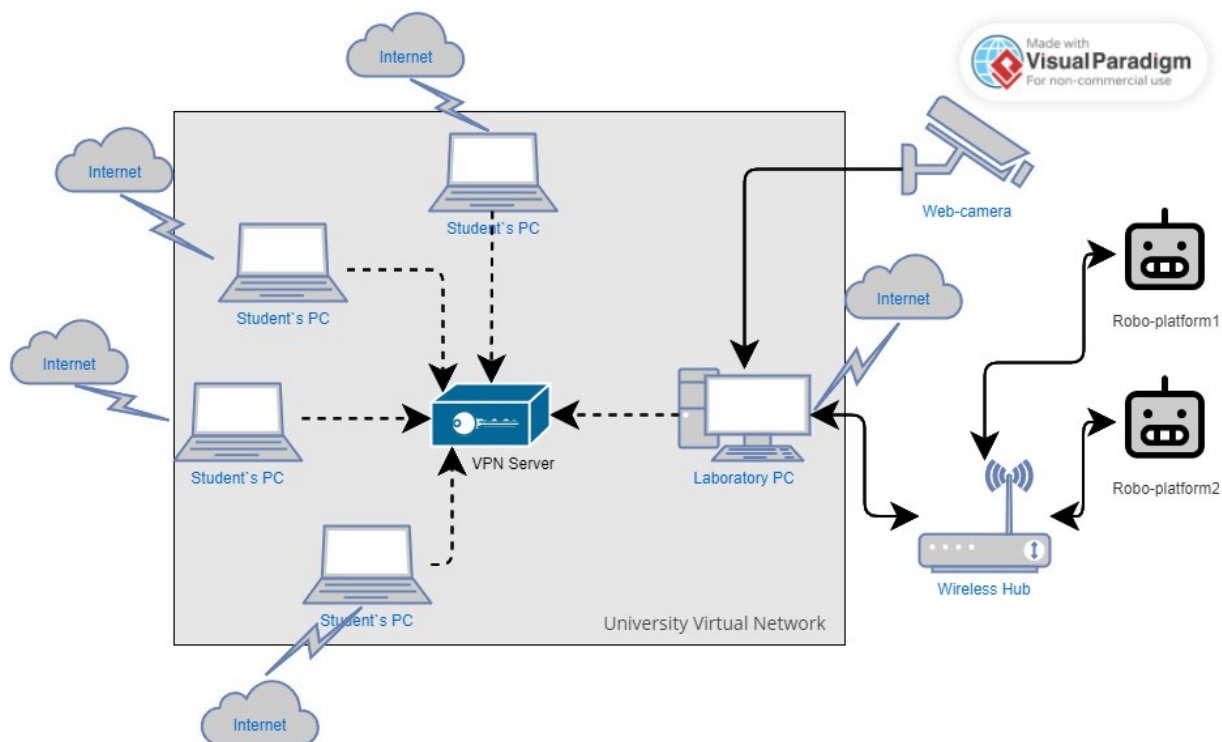


Figure 1. The general scheme of the working process organising.

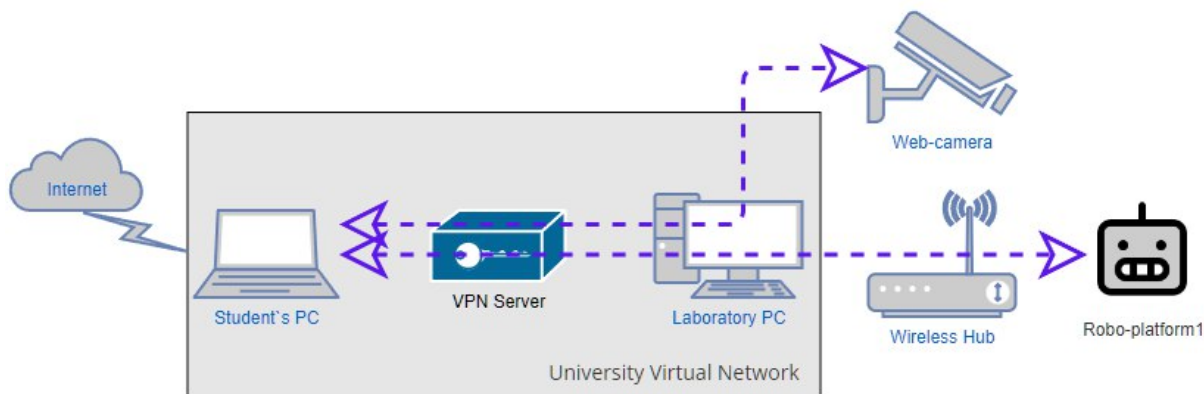


Figure 2. The data transfer when a student works with a robot.

3. Methods of learning and task examples

Practical work of students in basics of robotics was built according to such steps:

- 1) theoretically analyzing the problem and choosing the robotics system components;
- 2) creating a model of the robotics system in the GearsBot environment;
- 3) developing and testing an algorithm for the robotics system operating in the virtual environment;
- 4) converting the algorithm into MicroPython command system and testing it with the remote-controlled robot;
- 5) updating the algorithm to take into account the features of the real environment.

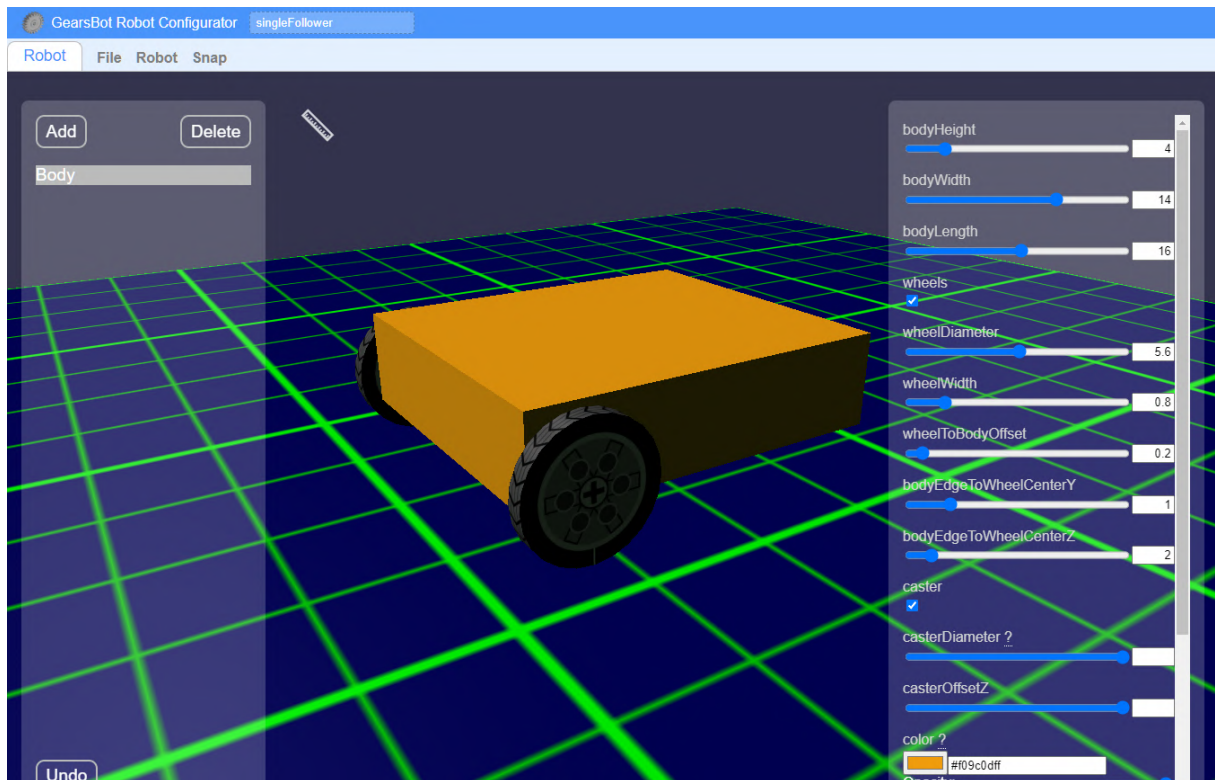


Figure 4. Student’s virtual model of the robotics platform.

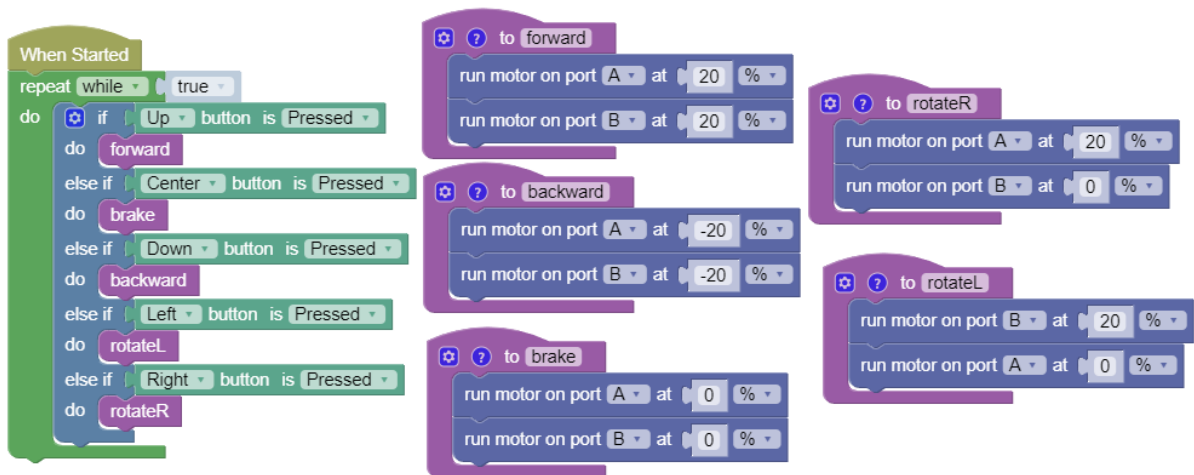


Figure 5. Student’s work example on the algorithm of manual control.

At the last step, the students proposed a correction to the rectilinear motion algorithm taking into account the different physical parameters of the motors (figure 8). It was also determined the need for feedback in the robot control system, namely the use of additional sensors (encoders) to determine the speed of rotation and the distance travelled by the motors, and spatial orientation sensors.

We have discussed the first task in our series of laboratory works that are based on learning

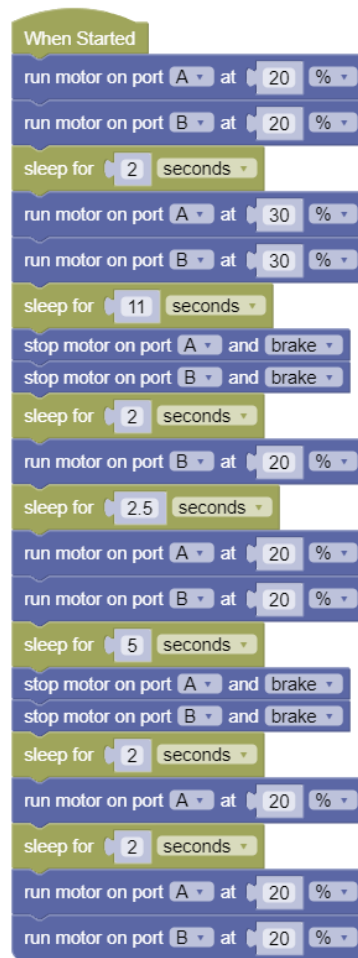


Figure 6. Student’s work example on the algorithm for automatic robot movement along the given track.

researches. The following tasks develop students’ understanding of the limitations of virtual environments in comparison with the real world, the importance of feedback and contribute to the acquisition of professional competences in building the structure of an information system with robotic elements, algorithms for data processing and management in such a system, methods of testing and debugging the system. As examples of the questions that are worked out during the laboratory classes of this introductory course, we can cite: mastering the methods of synchronizing the motor operation and data processing from sensors in real time; building intelligent algorithms for robot self-correction; approaches to spatial orientation of the robot in particular computer vision; intelligent algorithms for the robot’s execution of tasks on the terrain (finding a way, creating a map, etc.).

4. Surveys and assessment

A survey was provided to verify the impact that our course do on students’ competencies and their professional viewpoints on the problems in robotics.

Two groups of students have taken part in survey. The first one (group 1) – students of third year of study, who had not studied this course at the moment when survey was conducting (9 persons). This group was suggested to answer questions of the common questionnaire (table 1).

```

#Control ports initialisation
import time
from machine import *
m11 = Pin(32, Pin.OUT)
m12 = Pin(33, Pin.OUT)
m21 = Pin(25, Pin.OUT)
m22 = Pin(26, Pin.OUT)
pm1 = PWM(m11,duty=0)
pm2 = PWM(m21,duty=0)

# Movement forward
def forward_time(power,ms):
    m12.off()
    m22.off()
    pm1.duty(power)
    pm2.duty(power)
    time.sleep_ms(ms)
    pm1.duty(0)
    pm2.duty(0)

# Movement backward
def backward_time(power,ms):
    m12.on()
    m22.on()
    pm1.duty(power)
    pm2.duty(power)
    time.sleep_ms(ms)
    m12.off()
    m22.off()
    pm1.duty(0)
    pm2.duty(0)

# Clockwise rotation
def osi_right_time(power,ms):
    m12.off()
    m22.on()
    pm1.duty(power)
    pm2.duty(power)
    time.sleep_ms(ms)
    m22.off()
    pm1.duty(0)
    pm2.duty(0)

# Counterclockwise rotation
def osi_left_time(power,ms):
    m12.on()
    m22.off()
    pm1.duty(power)
    pm2.duty(power)
    time.sleep_ms(ms)
    m12.off()
    pm1.duty(0)
    pm2.duty(0)

```

Figure 7. Student's MicroPython code for manual robot control.

```

# Movement forward with correction
def fl(power,ms):
    m12.off()
    m22.off()
    left_wheel = 0.9
    l_w_s = power * left_wheel
    pm1.duty(int(l_w_s))
    pm2.duty(power)
    time.sleep_ms(ms)
    pm1.duty(0)
    pm2.duty(0)

```

Figure 8. Student's MicroPython code for automatic robot control.

We studied the current stay of students viewpoints on robotics problems and their views on the importance of this field. The same questions were suggested to the students of the fourth year of study (group 2 – 6 persons), who had completed the “Robotics Fundamentals” course. We tried to see the changes in students professional viewpoints as a result of our course studying. Students of group 2 was also asked to answer the second questionnaire (table 2) that show us the information about competencies had been mastered by students. We need to underline that it was the survey, but not the test of educational achievements. There were not “correct” answers, we tried to understand students’ viewpoints on robotics as a field of research and on the quality of training in our course. The survey was not anonymous, because there were not asked any confidential information or direct rating for the course and the teacher.

5. Results and discussions

Students have mastered the required competences and learning results according to standard of the “Information systems and technologies” speciality as a result of the educational process in the “Robotics Fundamentals” course. It was shown in grading process according to study programme of the course. Pedagogical observation of the teacher says about students’ high interest to the educational process and their activity.

Detailed analysis of our technology was done on the base of surveys results. The relative frequencies for students’ choices are shown in the table 1 and table 2. The size of our samples are small, so we need to check the diapason of values that is statistically significant. Using the null hypothesis tests is not the trend of modern statistical analysis, especially for small samples, because of a lot of assumptions. This question was discussed in details in [11]. So we used the method of modelling based on the combinatorics to evaluate the limits of significant values for students’ choices relative frequencies.

There were done simulations with the model for single answer questions at significance level 0.05. Questions 5 (with 4 independent items for choice) and 7 (with 5 independent items for choice) were analysed for sample size of the group 2. There was detect that the value of relative frequency for students’ choice is statistically significant only if it is equal to 1,0. So, the fact that students have named the remote controlled robot as the most efficient element of didactic tools is statistically significant. But we can’t do any conclusions according to students’ answers for the question 7.

The similar models have been built and used for the multiple choice questions with three choices and unlimited number of choices. The values, which are statistically significant, are highlighted in bold in the table 1 and table 2.

According to the analysis of relative frequencies for students’ choices (table 2) we can conclude on the base of question 6 that construction of robot control logic and theoretical foundations of robotics were not some challenges for students while studying the course. We can also see from the question 2 (table 1) that students, who have already studied the course (group 2), understand the importance of theoretical basis in principals of robotics as one of the tasks of study. Before studying the “Robotics Fundamentals” course students (group 1) saw the computer vision as the most important task for the course (table 1, question 2) and as the most important field of robotics science (table 1, question 3). We believe that while mastering in robotics students have understood the complexity of tasks, which must be solved to create a robotics system. They have understood the importance of theoretical basis in the field of study and needs to develop their mastering in specific fields, such as computer vision, by studying the appropriate additional courses or by self-study.

We can also see (table 1, question 1) that after studying the course students understand the possible using of robotics and automation in real business. The importance of developments in the field of power cells for autonomous robots is underestimated. Therefore, it is advisable to pay attention to this issue in our course future development.

Table 1. Common questionnaire (English translation from Ukrainian).

Question	Options	Group 1 choices	Group 2 choices
1. Choose the three most important arguments regarding the inclusion of a robotics course in the bachelor’s training program in information systems and technologies	the importance of robots and automation in modern business	0.56	1
	the importance of robotics in the future	0.22	0.5
	development of programming skills	0.44	0.5
	development of algorithmic thinking	0.67	0.17
	study of methods of combining information system components (hardware)	0.67	0.5
	study of features of software for robots	0.44	0.33
2. Choose the three most important tasks of the course “Robotics Fundamentals” in the speciality “Information systems and technologies”	understanding of the basic principles of robotics	0.33	0.83
	acquiring the ability to program robots for various tasks	0.33	0.67
	acquiring the ability to develop and implement practical robotics projects	0.44	0.5
	improving the skills to work in a team when solving complex tasks	0.11	0.17
	an overview of the current state and prospects for the development of sensors	0.11	0.17
	an overview of the current state and prospects for the development of movement devices and manipulators	0.11	0
	an overview of the current state and prospects for the development of computer vision algorithms (object recognition)	0.78	0
	studying approaches to the application of artificial intelligence elements for robot control	0.33	0.33
	study of approaches to automation of management processes based on information systems	0.44	0.33
3. Choose the three most important tasks associated with robotics at the current stage of its development	creation of algorithms for controlling drives that provide robot movements	0.44	0.5
	processing signals from sensors (computer vision)	0.78	0.5
	decision-making in unexpected situations (overcoming obstacles)	0.67	0.17
	creating a human-like robot design	0.33	0.17
	speech recognition	0.33	0.5
	improvement of mechanics of manipulators	0.33	0.33
	improvement of sensors	0.11	0.5
improvement of energy supply means for robots	0	0.33	

According to questions 8 and 9 (table 2), which were not obligatory we can show some examples of students answers (in translation from Ukrainian): there were acquired skills of “creating the code for the robot to execute it, it was also interesting to learn about robotics itself”; “I learned to control the robot with the help of commands”; “improved knowledge of programming”; there will be useful in future “understanding how it all works, is interconnected and how you can create it even at home!”, “hardware”, “knowledge of sensors for various

Table 2. Professional questionnaire (English translation from Ukrainian).

Question	Options	Group 2 choices
4. Choose the three most important directions for improving the course	additional video lessons	0.17
	additional textual educational materials	0
	availability of remote management of robots in self-study time	0.83
	automation of tracking the quality of task performance (Has the robot completed the assigned task?)	0.5
	automatic return of the robot to the starting position	0.83
	application of a virtual robot for independent work	0.67
5. Which educational resource was, in your opinion, the most effective? (single answer)	presentations	0
	GearsBot online environment	0
	documentation for the technical components that were applied	0
	remote-controlled robot	1.0
6. What were the main challenges you faced while studying this course?	maintaining the class schedule	0.17
	the programming language	0.67
	construction of robot control logic	0
	theoretical foundations of robotics	0
	understanding of physical processes in sensors	0.17
	receiving and using data from sensors in the program	0.17
	taking into account the obstacles of the real environment in the robot control algorithm	0.17
	consideration of possible sensor errors in the real environment	0.33
7. What turned out to be the most unexpected and interesting while studying the course? (single answer)	I can create a robot myself	0.33
	the robot can be programmed in Python	0.17
	control and programming of the robot can be carried out via the Internet	0.5
	unexpected obstacles must be taken into account when programming the robot	0
	the accuracy of sensors and motion devices is limited and affects the robot's performance of the task	0
8. What specific knowledge or skills have you acquired regarding robot programming? (open answer)		–
9. What information from the robotics course will be most useful to you in the future? (open answer)		–

household robots”, “information about various parts and sensors that can be used in work”, understanding “how robots can be integrated into learning”.

6. Conclusion

The courseware for the “Robotics Fundamentals” course for students of the “Information Systems and Technologies” speciality has been prepared and introduced. The educational process was organised as full distance learning and was supported with all traditional technologies such as learning management system, video-lectures and online consultations in Microsoft Teams. The practical work in this course is organised according to real business process in the robotics field from designing the structure and choosing components of the robotics system through simulation in virtual environment to testing the system in the real physical environment.

The key component of this course is the laboratory with remote controlled robots that provides low-level access to components; is available for self-creation by a student; use Internet connection for access to all remote components; is accessible from any students’ operating system and under any Internet provider.

The survey was conducted among students who had studied this course and who had not studied it yet. As the results of this survey, pedagogical observation and educational testing, there have been concluded: the course had achieved its purpose; the remote controlled robots is the key element of the courseware in the students opinion; after the completion the course students had understood the importance of theoretical basis in the field of study and needs to develop their mastering in specific fields, such as computer vision, by studying the appropriate additional courses or by self-study; after studying the course students understand the possible using of robotics and automation in real business.

The prospects of future work is continuous development the “Robotics Fundamentals” on the base of students’ feedback; creation of elective courses in specific fields of robotics, in particular computer vision.

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Experience of conducting integrated irregular classes in robotics

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Abstract. In the modern world of electronic devices, a person can bring to life any projects that make their life more comfortable and safe. The basis for such solutions is robotics. Creating and programming a robot today is quite simple. We offer the experience of conducting long-term projects that can take place in summer camps, scientific studios, and extracurricular clubs. The uniqueness of such activities lies in the combination of various types of work that help explore the topic and conduct scientific and technological research. Mastering robotics technology and understanding the principles of their operation is an important aspect of preparing modern children for a safe life in a high-tech world and successful self-realization. The foundation for the study and effective application of these technologies is mathematics, physics, engineering, and programming. Therefore, STEM education, aimed at developing competencies demanded in society, increasing motivation to study traditionally challenging subjects of the natural-mathematical cycle, is of particular importance. The peculiarity of this approach to education is project activity and transdisciplinarity, contributing to the formation of teamwork skills, critical thinking, and a comprehensive understanding of the researched problem. The article presents the experience of a volunteer project to teach robotics to children from Ukraine. Organizational conditions for conducting classes, typical difficulties, examples of projects, and the lesson scenario are provided. The proposed approach to organizing education is based on years of practical experience and can be used by educational institutions and non-profit organizations.

1. Introduction

The modern high-tech society demands a deeper understanding of the principles of digital technologies, which is a prerequisite for successful self-realization and a secure life in the present world. The widespread adoption of technologies such as artificial intelligence [1], immersive technologies and metaverse [2], blockchain [3], the Internet of Things [4], big data, and others has radically transformed all spheres of society's life, as captured by the concept of Industry 4.0. Technologies and professions where engineering abilities play a primary role come to the forefront. Professionals with skills in modern technologies and a creative approach to problem-solving are in demand in the job market. In response to societal demands, the new challenges for the education system include raising the level of scientific, technical, and technological knowledge for all layers of the population, professionals, and future specialists in various fields, including teachers and students. The increasing quantity and quality of technologies, especially computer technologies, make integrated learning, with STEM (Science, Technology, Engineering, Mathematics) projects using robotics devices, a relevant educational approach [5,6].



The foundation of such education includes mathematical education, physics, programming, construction, and their integration. The integrative scientific approach forms the basis for project work and teamwork. This educational approach allows increasing students' motivation to acquire theoretical knowledge based on practical activities and fosters an understanding of science as a factor in technical and socio-cultural progress [7, 8]. According to the Concept of the Development of Natural and Mathematical Education, the goal of STEM education is "the development of personality through the formation of competencies, a natural-scientific worldview, worldview positions, and life values", particularly through a transdisciplinary approach [9].

However, recent events such as COVID-2019 and the war in Ukraine have significantly impacted the education system as a whole, directly affecting all participants in the educational process [10]. Strong stress, lack of communication with friends, new places and living conditions, challenging household conditions, including the absence of electricity and the internet, have become the realities of everyday life for many Ukrainians. The most vulnerable category is children, some of whom have lost their relatives, were forced to move, and start living in completely new circumstances (different city or country, different teachers or online learning, different peer environment, and lack of communication, among others). Scholars are focusing on finding ways to overcome learning losses [11, 12] especially in the process of studying mathematics, traditionally challenging to master [13]. Mathematics plays a significant role in the "integrative approach to the implementation of natural and mathematical (STEM) education" [9]. The creation of STEM education centers, where displaced children can communicate with their peers facing similar situations; meet in real life, not just online; collaborate on interesting creative tasks; acquire new knowledge; enhance their skills; and define their preferences and perspectives for the future and profession is an extremely important task. At the same time, researchers conducted a systematic literature review, revealing that STEM education develops skills that give migrant families access to economic and social benefits and contribute to social innovation processes in destination countries [14].

Another important component of STEM education is the integration of natural knowledge content, its practical orientation, and involving students in scientific research [15]. Integrated STEM projects are one type of organizing students' educational and cognitive activities both within and outside the school. The combination of experimental work with learning enhances research skills about the surrounding world and helps explore the world from a scientific and factual standpoint. Studying the operation of devices, their construction, and the inventive approach to prototyping shape students' scientific worldview and contribute to the development of cognitive activity. While working on an integrated learning project, children gain basic knowledge about the operation of devices and the physical laws that govern them. They develop a generalized understanding of system functioning, gain experience in conducting experiments, and explore the art of invention. Children acquire initial knowledge of modeling, programming, computer data processing, and study the physical principles of sensor operation, their limitations, and potential applications. Integrated learning projects are a form of organizing students' educational and cognitive activities within and beyond the school. Each session is focused on implementing a specific project and includes tasks related to research, construction, and programming. We have created and conducted a series of integrated robotics classes for children aged 10-16. The purpose of this article is to present the experience of conducting integrated classes for children. The organizational conditions for the sessions were as follows:

- Variable composition of participants.
- Different technical and software bases (MicroBit, Lego Mindstorm EV3, Zumi).
- Extended duration of the sessions: from 10:00 to 15:30.

The sessions have been held for over a year, once every two weeks. Depending on the number

of construction sets available, there are specific limitations on the number of participants (from 10 to 28). Group formation occurs through pre-registration. Students primarily work in pairs on projects. The sessions are divided into two parts with a break for lunch. The projects were constructed using micro:bit.

2. Description of the methodology

The majority of the projects outlined in the article are built using the micro:bit board, specifically designed for teaching programming and electronics. Therefore, prior knowledge of programming is not mandatory. Children learn programming in the process of creating devices. If programming skills already exist, working on the project helps enhance them. In the creation of projects, materials from basic micro:bit projects, NASA research projects, and Hacking STEM Microsoft projects were used. Therefore, if desired, one can explore the relevant materials, make changes, or expand upon the content of this course. The following list provides resources utilized for project activities:

- Hacking STEM Projects <https://learn.microsoft.com>.
- Online micro:bit editor <https://makecode.microbit.org>.
- micro:bit support site <https://microbit.org>.
- NASA school projects site <https://www.jpl.nasa.gov/edu/teach>.

Each project includes a prototype creation stage. The projects are chosen so that readily available materials found in every household can be utilized. Therefore, if necessary, the projects can be conducted in a remote format. In such cases, the built-in simulator at makecode.microbit.org is used during the programming stage. The outlined projects also have a medium-term duration, designed for activities spanning 4.5 hours. Hence, they can be applied during school breaks (STEM camps, workshops, etc.). Conducting sessions of this duration requires thorough preparation and planning. Different types of tasks should be alternated to keep the children engaged and vary their activities.

In the course of developing the sessions, we drew upon the extensive experience of the STEM school at Kherson State University [16, 17], but encountered the following challenges:

- Lack of methodological literature in Ukrainian: Absence of methodological literature in the Ukrainian language that provides a balanced presentation of the material necessary for the implementation of a specific project. Much of the educational literature and online resources for conducting sessions focus on specific aspects, such as emphasizing the principles of certain sensors and circuit construction (common in Arduino educational literature), physical laws, and measurements in physics, etc.
- Versatility of schematic implementation: It's noted that the same schematic can be used to implement various tasks, modeling real-life situations and requiring slight changes in the program. For example, the same schematic can be used to implement scenarios where a) a sick person presses a call button (state "button pressed" triggers LED flashing), or b) an alarm goes off when a safe is opened (state "button not pressed" triggers LED flashing). Thus, students are encouraged to not merely assemble the circuit and program step by step but independently propose changes for implementing different real-life situations, fostering a deeper understanding of the relationships and principles of the construction elements and commands in the program code. These tasks can be further complicated by adding sound signal capabilities to the schematic and program.
- Difficulty explaining sensor principles to students without physics background: The challenge of explaining the principles of sensor operation or certain technologies (e.g., radio, mobile communication) to students who have not yet studied physics or are engaged in

online learning, lacking experience in conducting laboratory work. The principle of radio operation was used in projects such as “Treasure Seekers”, “Space Journeys”, “Security System”, and others (descriptions of some projects are provided in table 1).

- Limited budget for preparation: The constrained budget for lesson preparation influenced the selection of projects and materials for experiments and construction within an affordable price range (examples of projects are provided in figure 1, figure 2).
- Long duration of sessions: Most robotics projects are designed to be completed within a single class period (from 45 minutes in schools to 1-2 hours in extracurricular clubs). Therefore, to maintain children’s attention over a long time, various types of activities and the organization of physical activity were used in each session. This involved incorporating construction and competitive stages. During the construction stage, children could unleash their creativity and engineering abilities, working in teams and using various tools and materials. The competitive stage allowed not only working at tables but also organizing physical activity, moving children outside (if circumstances and weather permit). For example, treasure hunting took place outdoors, where children searched for a hidden beacon that emitted signals; model car races were tested on a sloping sidewalk surface, and soil moisture measurements were taken on lawns adjacent to the building.
- Variable group composition: Each session introduced students who came for the first time, had never engaged in robotics before, or, conversely, attended similar sessions regularly, desired to join, or were brought by parents under various circumstances. Since children meeting in such sessions may be unfamiliar or not well-acquainted with each other, a crucial stage is introduction. Therefore, we use so-called “Ice Breaker Games” for this purpose. Project work typically occurs in small groups or pairs, making the creation of an atmosphere of trust and good interaction vital for organizing teamwork.

Table 1: Examples of projects implemented on MicroBit within the “Ukraine Hacker-School” classes.

Name	Equipment for one team	The main stages of the lesson
Treasure hunters	MicroBit – 1 pc.; + one microbit the teacher uses as a beacon (transmitter) to search for “treasures”	<ol style="list-style-type: none"> 1. Introduction. Formulation of the problem. 2. Introduction to MicroBit. 3. Getting to know the radio. 4. Exchange of messages: establishment of a transmitter-receiver pair (group), sending a signal, receiving a signal, reacting to the received signal. 5. Studying the strength of the signal and measuring the distance over which it acts. 6. Beacon programming. 7. Search for a radio signal at a distance (search for “treasures”). 8. Summing up.

Name	Equipment for one team	The main stages of the lesson
Security system	MicroBit – 2 pcs.; magnet – 1 pc.	<ol style="list-style-type: none"> 1. Introduction. Formulation of the problem. 2. Introduction to MicroBit. 3. Magnetometer, its properties. 4. Measurement of magnetic force indicators and measurement of the distance over which it acts. 5. Alarm programming. 6. Work with the radio. 7. Message exchange: setting up a transmitter-receiver pair (group), sending a signal, receiving a signal, reacting to a received signal. 8. Summing up.
Space travels	MicroBit – 2 pcs.; inflatable balls – 4 pcs.; straw for cocktails – 1 pc.; fishing line; paper (masking) tape	<ol style="list-style-type: none"> 1. Introduction. Formulation of the problem. 2. Building a rocket. 3. Improvement of the rocket design. 4. Introduction to MicroBit. 5. Getting to know the accelerometer. 6. Equipping the rocket with an accelerometer and setting the pair: “rocket – flight control center” (radio). 7. Programming the interaction between the rocket and the center. 8. Summing up.
Automatic watering of plants	Micro:Bit – 1 pc.; metal clips or stripped wire ends for installation in the ground – 2 pcs.; wire for connection to Micro:Bit – 2 pcs.; straw for cocktails – 1 pc.; servo motor – 1 pc.; paper cup – 1 pc.; paper (masking) tape for fixing the pump structure; plant – 1 pc.	<ol style="list-style-type: none"> 1. Introduction. Formulation of the problem. 2. Study of the problem. 3. Introduction to MicroBit. 4. Construction of the irrigation model. 5. Determination of soil moisture, construction of a table for different states. 6. Acquaintance with the servo motor, its programming. 7. Summing up.
Robot hand	MicroBit – 1 pc.; servo motor – 1 pc.; cocktail straw – 1 pc.; threads, cardboard for a model of a hand, fingers	<ol style="list-style-type: none"> 1. Introduction. Formulation of the problem. 2. Construction of the grip (End Effector). 3. Construction of the finger structure. 4. Introduction to MicroBit. 5. Servo motor programming. 6. Arrangement of fingers in a hand model. 7. Finger interaction programming, rock-paper-scissors game. 8. Summing up.

Name	Equipment for one team	The main stages of the lesson
Auto racing	MicroBit – 1 pc.; engine and driver – 1 pc.; wheel – 1 pc.; materials for the base of the machine (cardboard, wooden skewers, sticks, toothpicks); plastic covers for wheels: rubber ring for wheels	<ol style="list-style-type: none"> 1. Introduction. Formulation of the problem. 2. Construction of the machine structure. 3. Testing of various designs, improvement of the model. 4. Races of mechanical engines. 5. Acquaintance with the operation of the engine. 6. Introduction to MicroBit. 7. Engine programming. 8. Installing the motor on the model and racing with an electric motor. 9. Summing up.

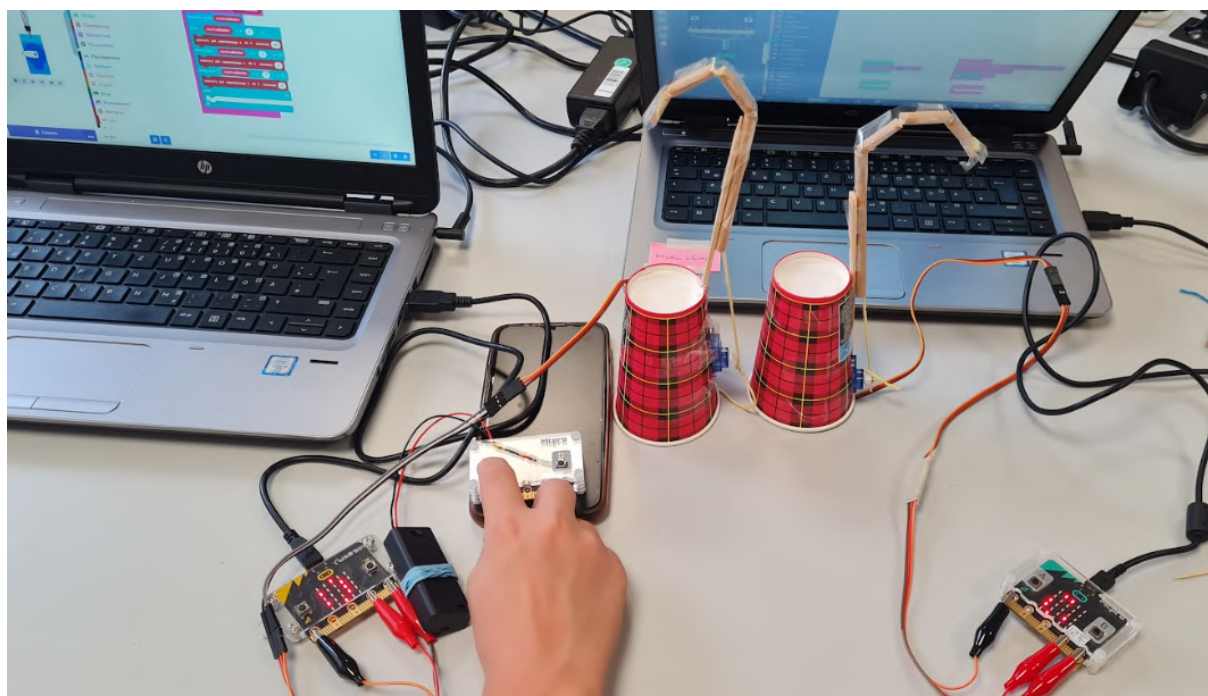


Figure 1. Project “Robot Hand”.

During such games, children get acquainted, share some information about themselves, and learn certain details about each other. It’s also a great opportunity to make activities more dynamic, moving away from the work desks. The challenge in programming classes is that most of the time, children are at their workstations and move very little. Therefore, incorporating icebreaker games involving passing a ball or transferring an object adds variety to physical activity.

Games at the beginning of the session can also be used to activate prior knowledge. In this case, game topics are chosen that are relevant to the session’s theme.

Throughout the session, there may be a need to select one or two children for specific tasks, such as constructing a prototype or forming a team to work on a 3D model. In such cases, we employed the game “Rock-Paper-Scissors”. In a playful manner, children competed to assemble their teams.

Examples of “Ice Breaker Games”.

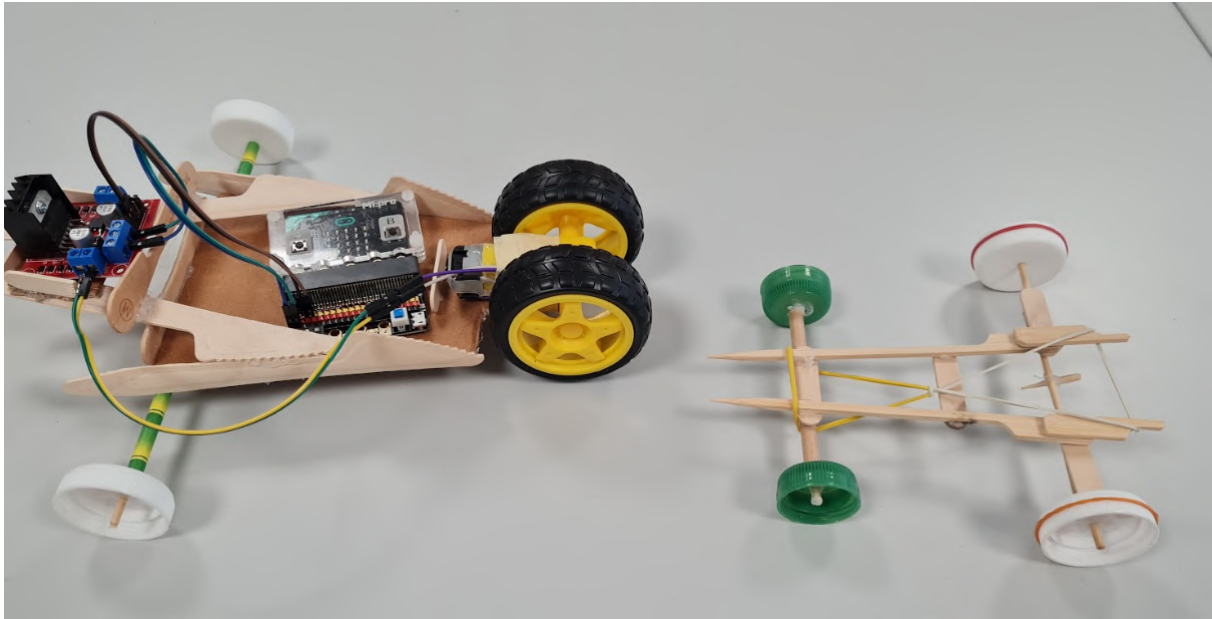


Figure 2. Project “Auto racing”.

- Introductions game: Besides their name, each player mentions a quality (character trait) that starts with the first letter of their name or corresponds to it. For example: Larry — loyalty, Boris — bravery, Renata — reliability, and so on..
- Object comparison game: Besides their name, each player states a quality they would have if they were an object. For instance, if their name were a “cup”, they might say they’d never break, have an appealing design, etc.
- Knowledge activation game: Show (or explain) a word. Children take turns gesturing the word without speaking, while others try to guess it. Another variation is explaining the word without using the word or related terms. Examples of words are chosen based on the theme: sensor, robot, alarm, mystery, code, program, testing, micro:bit, programmer, experiment, bank, safe, security, access, safety. Explanation: Information transmission is only possible when the transmitter-receiver system shares a common set of commands (understandings). In case of misinterpretation, information may be lost. Conclusion: Clearly formulate definitions and use terms in professional communication.
- Knowledge activation game (tactile edition): Place various objects or their parts in an opaque bag. Ensure there are items not commonly encountered in a child’s daily life. Examples include a dowel or its fastener, portable tools, an old model mobile phone, or an unusually shaped flashlight. Blindfolded, a child selects an item and, without looking at it, describes its characteristics, attempting to guess its name. Explanation: Our brain functions like modern neural networks. We can accurately name an object if we have seen or worked with it before (data in our knowledge base). If there is no such experience, we try to match its characteristics with past experiences by naming objects we already know. Conclusion: Learn something new, enrich your knowledge base.

Let’s consider in more detail the typical stages of conducting classes.

The first stage is the **introductory word**. At this stage, motivation is created, the task is set, and knowledge is updated. Tasks are set that correspond to the goals of sustainable development [18]. The problem is explored from various perspectives: its significance for

individuals, the environment, protection against natural disasters, and the impact of random factors. This is an important stage for future modeling. Possible project implementation options are considered here, critical questions are identified, and good ideas for further construction and implementation of models are recorded. It is advisable to conduct 'Ice Breaker' games at this stage.

The second stage is **modeling and prototyping**. Depending on the project, the prototype can be the electronic circuit based on micro:bit (for example, in the alarm project). In this case, the main theme of the research becomes the perception and processing of information, the topic of sensors and their characteristics, the transformation of physical signals into electrical ones, their fixation, and analysis. There are also projects where it is possible to build a design model (prototype) from readily available materials (for example, a car, a robot arm, a safe). Such a model is built to test the basic functionality of the created system. It simulates the operation of real devices and facilitates understanding of basic design and engineering constructions. An extension of the modeling stage, depending on the available materials and technical capabilities, is the construction of 3D models and their printing. This can be done in teams. Some children create a functional prototype, and others create a 3D model that can be printed. At the prototype construction stage, experimental testing of design and engineering ideas takes place. The variety of available materials allows operating with concepts such as construction reliability, joint stiffness, degree of freedom, etc.

At the beginning of the prototype creation stage, it is necessary to remind children of safety rules. Technological development at the modern stage is so rapid that most household appliances do not go through the repair stage, or the device is created without the possibility of repair. For example, modern phone batteries are already built-in and cannot be replaced. Sometimes it is easier to replace the device with a new model with expanded functions than to repair it. Therefore, modern children do not have much experience working with various tools. It is necessary to remind them of the danger that can arise as a result of careless handling of tools (scissors, glue gun, applied materials, etc.).

The third stage is **programming**. Most of the presented projects do not involve complex software implementations. Their modification allows conducting experiments, comparing indicators under different input data and initial conditions. The main thing at this stage is not to 'give the correct answer' but to gain experience in finding the answer to the question based on the obtained data. In integrated classes, research and experimental work are given special attention. Children compare sensor readings under different conditions, analyze the data obtained. The results of experiments in different groups, as in any physical experiments, may be similar but not identical. At this stage, concepts such as measurement accuracy, error, input data, initial conditions, obtained result, range of values, etc., are introduced. Depending on the results obtained, children may receive individual tasks to refine input/output parameters or modify the device's design.

The final stage is **discussion and summarizing**. At this stage, it is necessary to update the information received, remind about new terms and concepts, outline further steps for improving projects, and receive/provide feedback on the completed project.

It is important for the classes to have a research-oriented nature, so we do not provide students with a ready-made solution. Instead, we suggest developing a specific construction, conducting a series of experiments, comparing team results, encouraging students to formulate hypotheses about the reasons for success or less successful outcomes, modifying the construction, and experimentally testing assumptions. For example, we provide a description of one of the classes.

3. Description of the lesson “Automatic plant watering”

The project was based on the Plant Watering project [19] from the makecode.microbit.org website.

1. Problem statement

The concept of a smart city and smart things is built on the ideas of human interaction with technology. Smart greenhouses are part of this concept. The use of smart greenhouses helps to use resources more efficiently, increase production volumes, and automate manual labor. Relevance to the Global Sustainable Development Goals [20]: Global Goal 15 – protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss. Task: take care of watering plants. We use soil moisture sensors to track patterns of moisture changes and how it affects our plants (crop).

2. Problem investigation

Discussion of the following questions:

- What is perception, how does a person perceive information provided by the world (senses, interpretation).
- How do robots and devices perceive the surrounding environment and communicate this to humans (sensors, data transmission).
- Limitations of perception – can humans and robots always correctly determine indicators (color blindness, sensory impairments, parameters of sensors, limitations of sensors).
- Information processing (data collection/transmission, big data).

3. Introduction to MicroBit

Micro:bit is specifically designed for teaching programming and electronics and does not require mandatory prior programming knowledge. Creating robots and smart devices based on Micro:bit allows children to acquire initial knowledge of modeling, programming, computer data processing, and understand the physical basics of sensor operation, their limitations, and application possibilities. Sensors installed on Micro:bit transmit signals, are read in the program, which converts this data into information. Children learn to program during the device creation process. If programming skills already exist, working on the project will help improve them.

The project is based on the concept of electrical conductivity and potential difference. The higher the soil moisture, the higher its electrical conductivity. The sensor is submerged in the soil up to a distance of 45 mm and measures the electrical conductivity of the soil between its contacts. The voltage at the output of the sensor is directly proportional to the level of measured electrical conductivity. The higher the soil moisture, the higher the signal level at the output of the sensor.

Discussion of Micro:bit sensors (light sensor, temperature sensor) and how other sensors, devices can be used (additional installation of motors). At this stage, it is important to conduct research on soil moisture and track Micro:bit indicators. Children make measurements in dry soil, wet soil, waterlogged soil, and water. All data is recorded in a table. Several measurements of the same environment are taken, and the indicators are averaged. Intervals of dry/wet conditions are determined. Children also conducted measurements outdoors, using a battery pack for the autonomous operation of Micro:bit. In this way, physical activity significantly compensated for part of the work done indoors.

4. Construction of the irrigation model – creating the design and prototype of the irrigation system based on a lever. Building a moisture measurement scheme. Testing the system (figure 3).



Figure 3. Project “Automatic plant watering”.

- 5. Introduction to the servo motor, its programming, and system testing – the irrigation system design may include a motor that activates when the soil lacks sufficient moisture (figure 4).

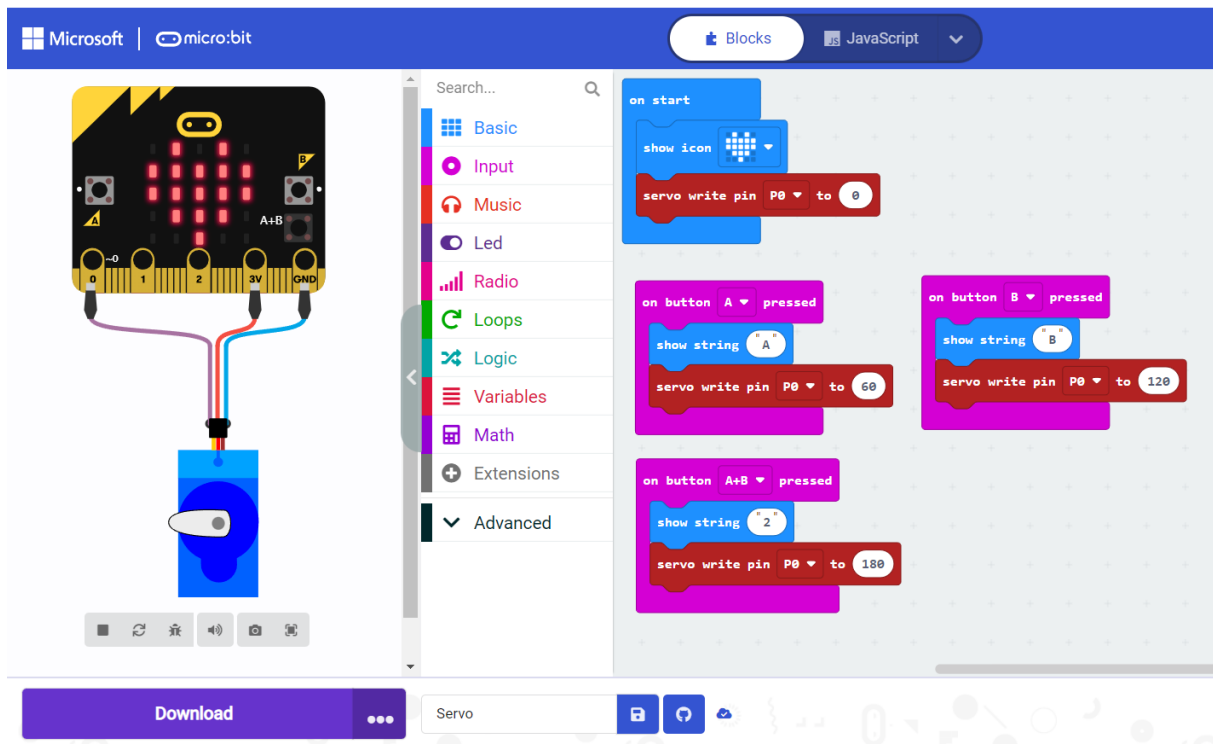


Figure 4. Program code for servo motor.

The motor can set a pump in motion to water the plant.

6. Summary. Definitions of new terms and concepts are updated:

- Science: data, research, electrical conductivity, potential difference, dynamics of soil moisture changes, regularity.
- Technologies: perception, sensors, information, limitations of perception.
- Engineering: reliability of the design, fixation, concepts of force, load, and lever (Archimedean lever).
- Mathematics: rotation angle, degrees, force ratios for lever operation.

Improvements to the projects can be made by using pumps of a different type. Since parents picked up the children at the end of the session, the students conducted a small presentation for them, explaining what and how was implemented and what could be improved.

4. Conclusions

The rapid development of technologies such as robotics, artificial intelligence, the Internet of Things, immersive technologies, and others, along with their widespread integration into all aspects of societal life, has led to qualitative changes in the economy, culture, and social life. This poses new challenges to the education system in terms of raising the level of technological knowledge for professionals in various fields and ordinary users, as well as preparing children for a safe life and successful self-realization in the high-tech world of the future. One effective approach to achieving these goals is integrated STEM (Science, Technology, Engineering, Mathematics) education. Particular importance for mastering new technologies and understanding the peculiarities of their functioning and limitations lies in subjects such as mathematics, physics, programming, and engineering. STEM education harmoniously combines knowledge integration from natural disciplines, practical orientation of learning, a research-based approach, and project work. All of this helps increase motivation for learning, develop a deeper understanding of the interrelationships between different subject areas, and form soft skills such as teamwork and critical thinking. The analysis of publications also revealed educational losses, especially in the study of mathematics (learning losses), due to global challenges such as COVID-19 and war. These circumstances significantly increased migration worldwide. However, the analysis of scientific literature confirmed the positive impact of STEM education on migrant children. Taking into account the analysis of scientific sources and our own many years of experience in developing educational materials and conducting classes at the STEM School of Kherson State University, we have developed and conducted sessions for children from Ukraine as part of the volunteer project “Ukrainian Hacker School”.

Among the peculiarities of the sessions, we note the varied composition of the group at each session, the long duration (4.5 hours per session), different technical equipment, a limited budget, and additional materials for project implementation. There were difficulties in explaining the principles of device operation to children of a certain age group and the absence of appropriate educational and methodological literature. Most projects were implemented using micro:bit. Each session included specific stages, including an introduction, problem statement, games, research and problem analysis, acquaintance with devices and sensors, construction, programming, experiments, and design improvement, followed by a summary.

The proposed experience can be used, refined, and expanded by teachers, club leaders, students, and adapted for different target or age groups.

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Estimation of methyl orange dye's molar absorptivity using a photoresistor-based photometer

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Estimation of methyl orange dye's molar absorptivity using a photoresistor-based photometer

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Abstract. The need to further develop solar cell technology, particularly on dye-sensitized solar cells (DSSCs), drives absorption studies of various chemical species. In this study, absorbance analysis of methyl orange (MO) dye was performed using the adapted and modified photoresistor-based photometer of Adams-McNichol et al. [1]. The research aims to improve the stability of the reference setup, while maintaining the accuracy of absorbance results it yields. The methodology includes photometer fabrication, MO dye sample preparation, and the evaluation of MO dye's molar absorptivity in an aqueous solution. Results show that the estimated molar absorptivity of MO using the voltage readings from the photometer is close to the literature value, with a percentage error of 1.44%. This finding demonstrates that the modified photometer retains its effectiveness, as supported by the method repeatability measurements from six samples for each of the following MO concentrations: 0 μM , 40 μM , 45 μM , and 50 μM . Considering these results, the device may be useful in teaching light absorption to students as an alternative to the "black box" approach, and in exploring purified natural dyes that have potential applications in solar cell technology.

1. Introduction

1.1. Background and significance of the study

Absorption spectroscopy is one type of spectroscopic measurement where the transmitted light that has passed through a sample can be related to the sample's absorbance. The absorbance, A , varies per wavelength, λ , due to the chemical structure of the chemical species being observed [2]. The corresponding A per λ (in nm) gives an absorbance spectrum that indicates one or more peak absorbance wavelengths of a sample. Another important relationship that can be identified using absorption spectroscopy is between the sample concentration, c , and absorbance, A . An ultraviolet-visible (UV-vis) spectrophotometer is an absorption spectroscopy instrument capable of detecting these relationships from the UV to visible light range.

UV-vis spectroscopy has wide applications in physics, chemistry, biomedical research, and clinical research, making it a valuable part of the undergraduate curriculum for specific degree programs [3]. However, Kovarik et al. [4] stressed issues in teaching the absorption spectroscopy technique using commercial spectrophotometers. Modern UV-vis instruments allow fast measurement of absorbance and production of absorption spectra, yet, the measurement itself applying the concepts of light absorption is obscured from the learners. The unavailability of research-grade instruments poses an even greater challenge too.



At present, various researchers developed student-built photometers for narrow wavelength absorbance measurements. Much of the existing literature proposed low-cost, home or school-built devices that can be better used in explaining the absorbance of light, as well as address the lack of instruments to do so [3, 4]. These photometers vary in the components used and conceptual frameworks behind the device mechanism – a review of some existing literature is developed by Kovarik et al. [4].

The low-cost, accurate photometer by Adams-McNichol et al. [1] features component advantages over other student-built photometers. The proponents developed a photometer that exhibits a better performance than the other versions and offers the same advantages for pedagogical purposes [1]. It introduces students to the basic concepts and allows an experiential learning opportunity since the construction of the device requires only basic electronics skills from the students and the design enables the users to see the components responsible for reading the absorbance [1]. The device functioning as an alternative UV-Vis spectroscopy instrument can also serve as a tool in teaching light absorption that preludes light energy harvesting technologies such as solar cells. In particular, a dye-sensitized solar cell (DSSC) utilizes synthetic or non-synthetic dyes to enhance the capacity of the device to harvest light and convert it into electrical energy [5].

In this study, the researchers adapted the photometer design of Adams-McNichol et al. [1], applied modifications to its physical design, and assessed its performance through method repeatability and determination of molar absorptivity of a common synthetic dye in university laboratories: the methyl orange. The methyl orange (MO) is one kind of azo dye soluble in different homogenous solvents and gives an intense orange color that can be used as a dye, stain, and pH indicator [6]. It has a photo-reactive structure and does not degrade easily, making it a potential light harvester for DSSCs [7–9].

This research aims to improve the stability of the reference setup [1], while maintaining the accuracy of absorbance results it yields. First, the circuit design was transferred from the breadboard setup into a soldered printed circuit board (PCB), allowing more stable electrical connections. Second, since the LED color depends on the sample to be observed, a feature where LEDs can be replaced to study different colored solutions was enabled by placing copper coils in areas where the component terminals were located.

1.2. Theoretical background

Absorption of light by chromophore-containing molecules is a fundamental mechanism that explains natural processes like photosynthesis and energy harvesting techniques such as in solar-cell technology [10]. Fundamentally, absorption can be written in terms of intensity or the power per unit solid angle [11]. When light passes through a sample, the intensity of transmitted light, I , at any given narrow band of wavelength is less than the corresponding incident light, I_0 [11]. The capacity of a substance to absorb the incident light at a specified wavelength is measured by the quantity called absorbance. The absorbance, A , is expressed as the negative logarithm of the fraction of incident light that has passed through the sample, as shown in equation (1).

$$A = -\log\left(\frac{I}{I_0}\right). \quad (1)$$

Another important relationship is between the concentration, c , of the absorbing substance and absorbance, A . This is called the Beer-Lambert Law as shown in equation (2). This law defines A as the product of the molar absorptivity, ϵ , (“extinction coefficient” or “attenuation coefficient”) at a particular wavelength, the concentration, c , of the molecules being observed, and the path length, l , of light through the sample.

$$A = \epsilon cl. \quad (2)$$

Adams-McNichol et al. [1] have reported a student-built photometer following the standard components for absorbance measuring devices with a single visible color LED as the light source, a cadmium-sulfide (CdS) photoresistor (also called “photocell” or “light-dependent resistor”) as the detector, and a multimeter as the signal processor. There are different advantages in such application of photoresistors. Photoresistors are more sensitive in reading visible light intensity than photodiodes but less than phototransistors; however, of all the combinations of different sources and detectors for the homemade photometer, the simplest design in which electronic components are usually configured is that of an LED source connected to a photoresistor [1, 12, 13]. Also, the resistance of the photoresistor is proportional to the analyte concentration, allowing for a more intuitive understanding of the detector’s mechanism [4].

The proponents of the reference photometer applied physical principles in the circuit design to arrive at a linear response over a concentration range, which is expected from Beer-Lambert’s Law, and to compute an accurate molar absorptivity value [1]. In their quantitative validation of the photometer using Beer-Lambert’s Law, the derived absorbance equation is expressed as

$$A = -\frac{1}{b} \log_{10} \left(\frac{V_{sample}}{V_{bat} - V_{sample}} \frac{V_{bat} - V_{solvent}}{V_{solvent}} \right) \quad (3)$$

where V_{sample} and $V_{solvent}$ are the voltage drop readings across the 10-k Ω resistor when the cuvette contains a sample concentration and when the cuvette only contains the solvent, respectively [1]. The power supply’s voltage difference is V_{bat} , while $b = 0.765$ is the parameter called photoresistor slope unique to the electrical component employed in the research [1].

2. Methodology

The methodology employed in this research is composed of four subsections: first, the construction of the modified photoresistor-based photometer, where the design alterations as well as fabrication of the circuit board itself are articulated; second, the preparation of various MO sample concentrations; third, the measurement of method repeatability, and; fourth, the absorbance measurement of five different MO concentrations to determine the molar absorptivity of MO in aqueous solution.

2.1. Construction of modified photoresistor-based photometer

The circuit schematic diagram of the reference photoresistor-based photometer [1] was recreated in EasyEDA Software and then converted into a PCB layout. Figure 1 shows the top view PCB layout of the adapted and modified photometer design where the electronic components are also indicated. One necessary modification of the original design was the addition of copper coils. These coils were added to allow a changeable light source since the LED terminals can be temporarily inserted between the loops of the coils. Furthermore, the coils allow easier voltage reading using the alligator clips connected to multimeters, as the clips can cling more easily to the coils than to the electronic component terminals.

For soldering the electronic components at the bottom side of the PCB, the top view layout was mirrored and saved as an SVG file (figure 2). This mirrored layout was the input file for engraving the circuit using Shaper Origin, a Computer Numerical Controlled (CNC) machine that etches on different surfaces [14]. The components soldered were the 1-k Ω and 10-k Ω resistors, CdS photoresistor, and the three pairs of coils. Each pair of coils was allotted for every positive and negative terminals of each electrical component. Figure 3 shows the etched SVG layout at the bottom side of copper material, with soldered electronic parts.

After setting up the circuit board, the LED was adjusted to be directly facing the photoresistor. The specifications of the LED used in this study are detailed in section 2.2. Figure 4 shows the final working setup with the LED, disposable cuvette placed in position with

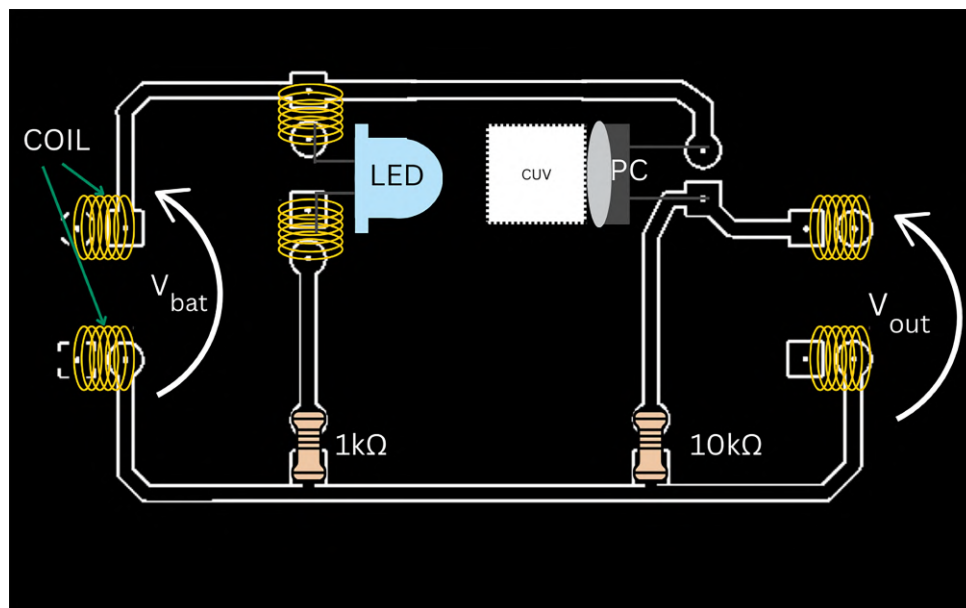


Figure 1. PCB layout of the adapted and modified photometer design [1]. The key components of the photometer are the LED, light-emitting diode; CUV, cuvette containing the analyte, and; PC, photocell or photoresistor.

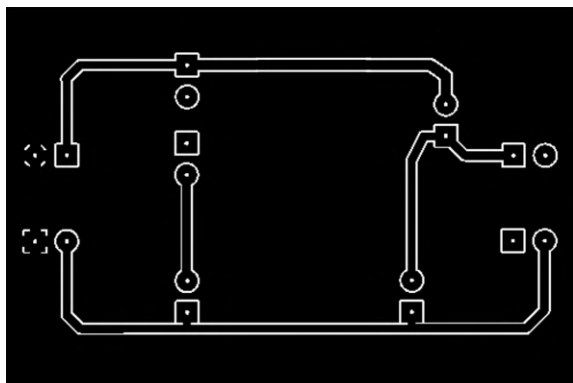


Figure 2. The SVG file of the modified photometer PCB layout.

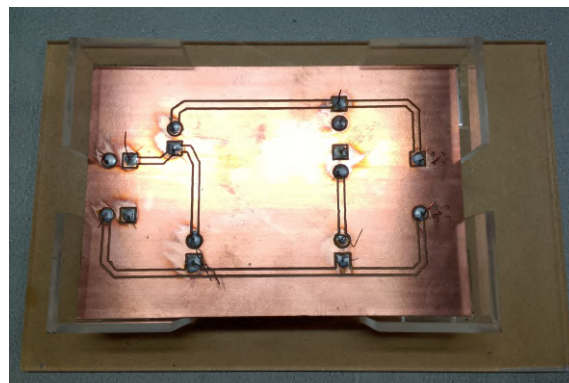


Figure 3. Etched SVG layout at the bottom side of copper, with soldered electronic parts.

a masking tape, and alligator clips that were connected to multimeters for ease of obtaining the power supply's and the 10-k Ω resistor's voltage readings. To minimize the stray light that can affect the accuracy of transmitted light detection, the photometer circuit board was covered with a black-painted acrylic box (figure 5).

In this research, it was observed that the open-circuit voltage reading across the power supply was different from the closed-circuit voltage. Hence, two multimeters were utilized (figure 6) to measure the voltage across the power supply (V_{bat}) and the voltage across the 10-k Ω resistor ($V_{solvent}$ or V_{sample}), simultaneously. Multimeter 1 was used to detect V_{bat} when the rechargeable battery was already connected to the circuit. On the other hand, multimeter 2 was used to detect $V_{solvent}$ when the cuvette contains distilled water without the MO dye, or to measure V_{sample} when the cuvette contains distilled water with the MO dye. Both multimeters have a HOLD function that was activated at the same time, every after five seconds of turning the power

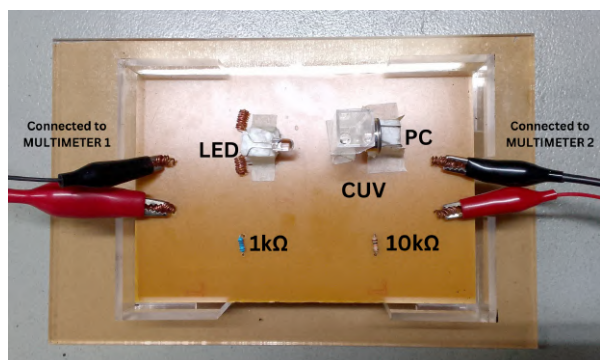


Figure 4. Top view of the PCB with a disposable cuvette.

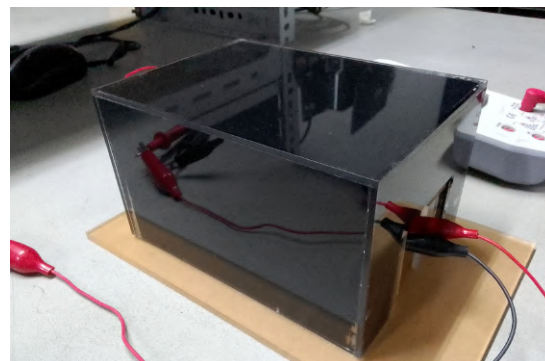


Figure 5. The photometer circuit board covered with a black-painted acrylic box.

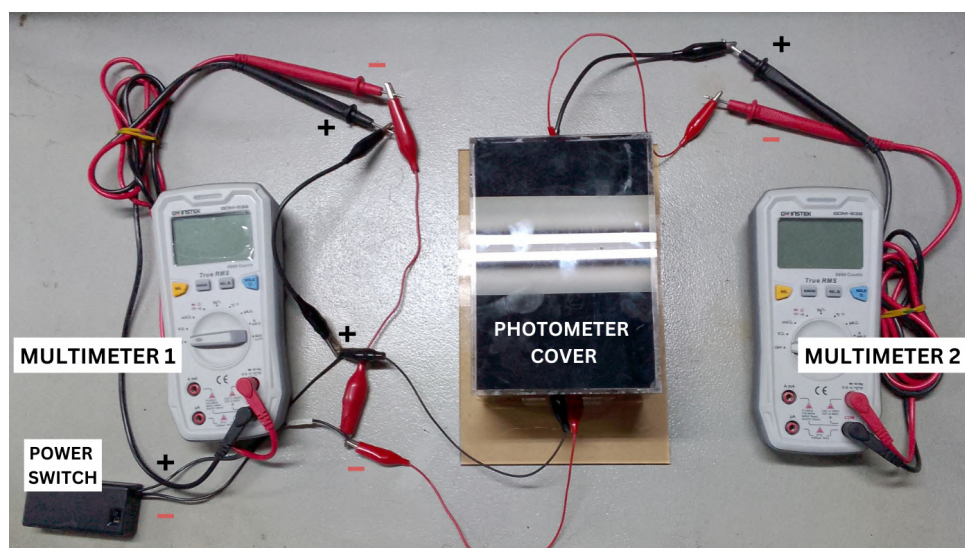


Figure 6. The modified photoresistor-based photometer.

supply ON.

2.2. MO sample concentration preparation

Before the measurements of absorbance were performed using the photometer, the samples were prepared. According to equation (3), the absorbance can be computed using the measured values of V_{bat} , $V_{solvent}$, and V_{sample} . To obtain measurement values for the $V_{solvent}$, at least 250 mL of distilled water was prepared, while for the V_{sample} , 100 mL of 0.1 M stock solution of MO was created. From the MO stock solution, a set of diluted solutions with concentration values of 40 μM , 45 μM , 50 μM , 55 μM , and 60 μM were made.

The molar absorptivity of MO in aqueous solution is $14,650 \text{ L mol}^{-1} \text{ cm}^{-1}$ with a peak absorbance wavelength of 464 nm [6]. This wavelength lies in the range of blue light, thus, a color blue indium-gallium-nitride (InGaN) LED with a peak emission wavelength of 460 nm [15] was used as a light source in the constructed photometer. Algar et al. [16] demonstrated that a colored solution's observed color and the color of light it absorbs the most are opposites in a complementary color wheel. Thus, using the spectrophotometric complementary wheel, it can be confirmed as well that an orange solution like MO in distilled water absorbs blue visible light

the most [15].

During the experimentations, 3 mL of either distilled water or diluted MO solutions were pipetted into a 1 cm × 1 cm × 4.5 cm disposable cuvette. This volume fills approximately 80% of the cuvette where the height of the liquid was sufficiently higher than both the blue LED and CdS photoresistor to maximize the transmitted light that passed through the sample.

2.3. Measurement of method repeatability

In this section, the modified photometer was used to find the absorbance of different MO concentrations: 0 μM , 40 μM , 45 μM , and 50 μM . To determine the repeatability of the absorbance measurement process, six samples were prepared for each MO concentration. Then, subsequent readings of the V_{bat} and $V_{solvent}$ or V_{sample} were conducted within the timeframe when the experimenter, method, location, and photometer setup were the same [17,18].

At zero concentration, the V_{sample} and the $V_{solvent}$ are the voltage readings across the 10-k Ω resistor when the cuvette contains distilled water without the MO dye. The V_{sample} is the voltage reading for each of the six samples, while $V_{solvent}$ is the average of all the V_{sample} readings. In order to obtain a nonzero absorbance using equation (3) and to determine the variability among the estimated absorbance values, the $V_{solvent}$ was differentiated as the average of all readings from the six samples across the resistor of interest.

For the three nonzero concentrations, the V_{sample} is the voltage measurement across the 10-k Ω resistor when the cuvette contains distilled water with MO dye. On the other hand, the average $V_{solvent}$ from the six readings at 0 μM was used as the $V_{solvent}$ in nonzero concentrations. Figure 7 shows the photometer when measuring the absorbance of 40 μM of MO in aqueous solution. The blue LED is turned ON, and a pair of alligator clips on the left side was connected to multimeter 1 for reading the V_{bat} , while another pair of clips on the right side was connected to multimeter 2 for measuring the V_{sample} . After completing the measurements for one concentration, the battery was also recharged to keep its open-circuit voltage at 9.0 V.

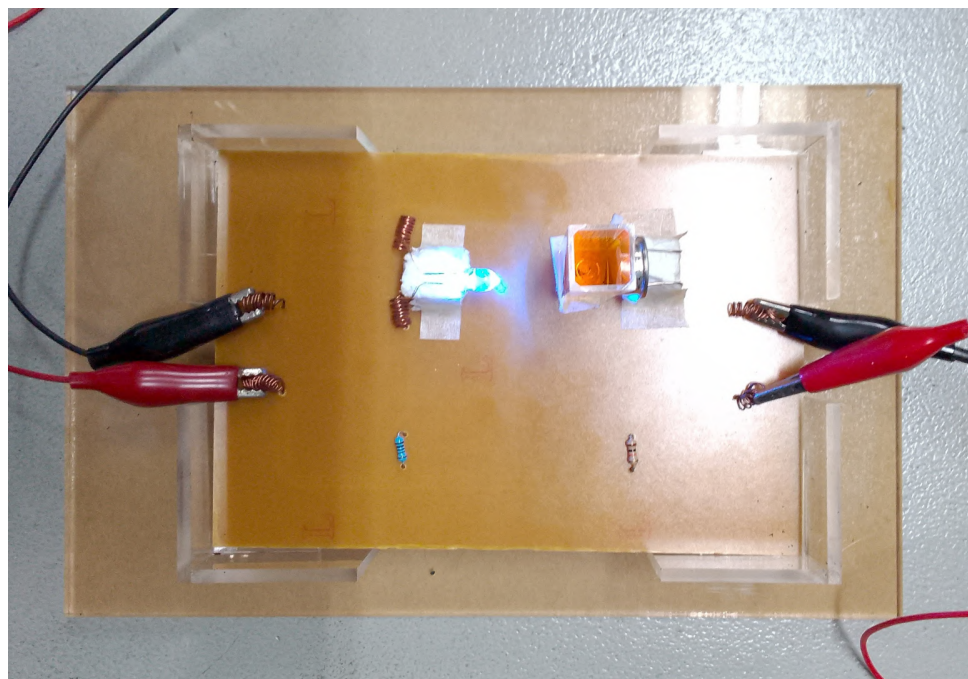


Figure 7. Sample absorbance measurement of methyl orange (40 μM) using the adapted and modified photometer.

The V_{bat} , $V_{solvent}$, and V_{sample} values for each concentration were substituted into equation (3) to approximate the absorbance [1]. Then, the standard deviation of the absorbance values was computed at a given concentration to check if the method was repeatable.

2.4. Determination of molar absorptivity

To utilize the modified photometer in estimating the molar absorptivity of the MO dye, the absorbance of five different MO dye concentrations (i.e., 40 μM , 45 μM , 50 μM , 55 μM , and 60 μM) were determined. Similar to section 2.3 for nonzero concentrations, the V_{sample} (i.e., the voltage measurement across the 10-k Ω resistor when the cuvette contains distilled water with MO), and the average $V_{solvent}$ at 0 μM were substituted into equation (3) to get the absorbance value per concentration. After this, the molar absorptivity was estimated by plotting the calculated absorbance against the five MO dye concentrations. The slope of the best-fit line from the graph is the molar absorptivity of the MO in distilled water.

3. Results and discussion

In evaluating the effectiveness of the adapted and modified photometer, the voltage readings (i.e., V_{bat} , $V_{solvent}$, and V_{sample}) from each concentration were first obtained and substituted to equation (3) to get the corresponding absorbance value [1]. Furthermore, to determine the closeness of the replicate absorbance measurements to each other, which is the measure of method repeatability, the standard deviations were calculated. Table 1 details the average absorbance values and standard deviation per MO dye concentration (i.e., 0 μM , 40 μM , 45 μM , and 50 μM).

Table 1. Repeatability measurement values for 0 μM , 40 μM , 45 μM , and 50 μM MO solutions.

Concentration c	Mean Absorbance	Standard Deviation
0 μM	0.01403	0.01503
40 μM	0.8644	0.03894
45 μM	0.9103	0.01918
50 μM	0.9505	0.02173

Table 1 shows that for each MO dye concentration, the standard deviations between the absorbance values were considerably low. This confirmed that there was an insignificant spread in absorbance results when one experimenter used the same procedure and photometer to analyze the MO dye concentrations multiple times [17, 18].

Next, to identify the molar absorptivity of the MO dye in an aqueous solution, the absorbance results at the concentration values of 40 μM , 45 μM , 50 μM , 55 μM , and 60 μM were plotted. Using the average voltage readings across the power supply and the 10-k Ω resistor, the absorbance values per concentration are presented in table 2. Moreover, figure 8 shows the absorbance versus concentration graph for the five MO dye concentrations.

The equation of the best-fit line on figure 8 reported a slope m equal to 14,861 L mol⁻¹ cm⁻¹. The literature value for MO's molar absorptivity in distilled water at 464 nm is $\epsilon = 14,650$ L mol⁻¹ cm⁻¹ [6], thus, a close value of molar absorptivity was determined with a percentage error of 1.44%. This proved that the modifications applied to the original photometer design to enhance its stability (i.e., through soldering the components on a PCB) and to improve other features (i.e., by adding copper coils and one multimeter) did not significantly affect the accuracy of the voltage measurements that are necessary to calculate the absorbance of a colored solution.

Table 2. The mean values of V_{bat} , V_{sample} , and $V_{solvent}$, and the calculated absorbance of different MO concentrations based on equation (3).

Concentration c	Mean V_{bat}	V_{sample}	$V_{solvent}$	Absorbance
40 μM	8.978	6.141	8.155	0.8635
45 μM	8.991	5.958	8.155	0.9100
50 μM	9.000	5.797	8.155	0.9502
55 μM	8.998	5.208	8.155	1.108
60 μM	9.000	5.128	8.155	1.136

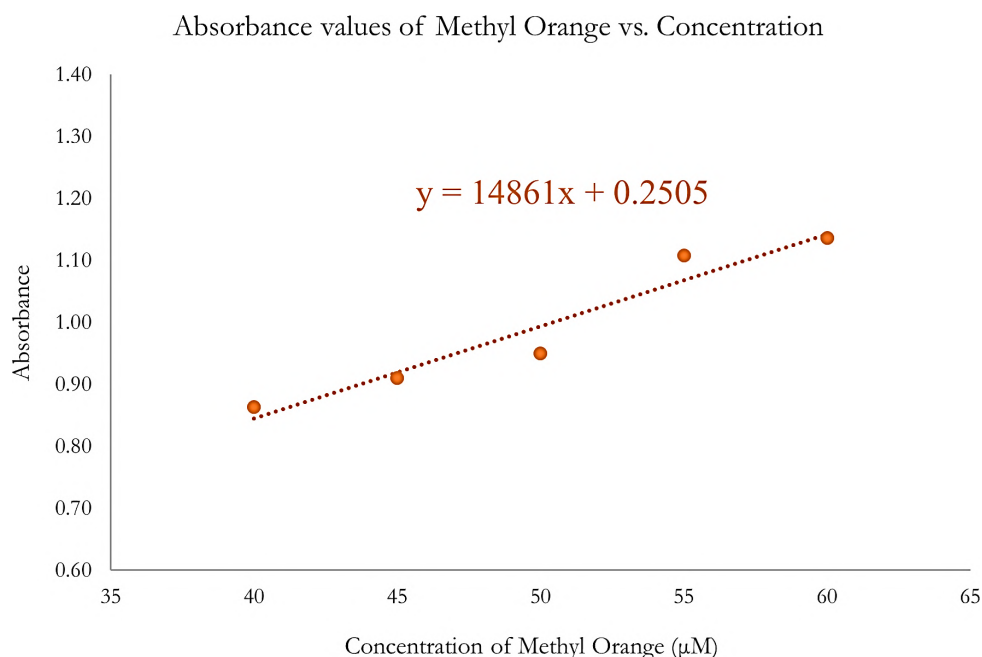


Figure 8. The absorbance versus MO concentration graph based on the mean of the voltage readings, $V_{solvent}$, V_{sample} , and V_{bat} .

The percentage error signifies not just the deviation of the experimental molar absorptivity value from the theoretical molar absorptivity value, but also the possible influence of various sources of error. The physical factors contributing to the sources of error, which were not measured but of considerable value, are the reflection of light from the walls of the photoresistor-based photometer and the defects on the plastic cuvette. On the other hand, there are also chemical factors that possibly influenced the measurements of data. Visual inspection showed that there are no presence of colloids and a homogenous solution of MO dye was achieved. However, the effects of MO powder and solvent purity in the achievement of the exact molar absorptivity value are noteworthy. The extent of these physical and chemical factors that may have contributed to the sources of error were not explored in this study.

4. Summary and conclusion

In this research, the photoresistor-based photometer of Adams-McNichol et al. [1] was reproduced with design alterations to create a more stable photometer and consider necessary device features for absorbance analysis. The setup was recreated by soldering the main electronic

components on a PCB. Then, copper coils were placed as holders of LED terminals and alligator clips to allow simple replacement of LED, based on the analyte's color, and for easier voltage readout. Another multimeter was also added across the power supply because the closed-circuit voltage across the battery was taken as the V_{bat} per reading, instead of the open-circuit voltage.

Using the modified photometer, absorbance values with validated precision and accuracy were derived from the voltages readings V_{bat} , $V_{solvent}$, and V_{sample} across the main components (i.e., the rechargeable battery and 10-k Ω resistor). This was evident in the insignificant variation of absorbance values from the method repeatability results, and in the comparable, estimated molar absorptivity of MO dye against the literature value [6]. In DSSC research, this capacity is also useful for identifying purified natural dyes with absorbance properties similar to photosensitizers like MO.

Moreover, the adapted and modified photometer may demonstrate effectiveness for studying absorbance of colored solutions in classrooms, which offers an alternative to "black-box" investigation, and for solving the lack of instrument to facilitate experiential learning. The possibility of using the device in an educational training may be a good prospect to receive approval and endorsement from teachers and students.

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Cognitive aspects of interaction in the “Human – Artificial Intelligence” system

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Abstract. The article, based on empirical and theoretical research, reveals the phenomenology of transformations of the human cognitive sphere when interacting with artificial intelligence. The analysis of the indicated changes in the cognitive sphere is carried out on the basis of the “Concept of cognitive multi-channel Human-Computer interaction” developed by us. The essence of this concept is that the interaction of the cognitive sphere of human and artificial intelligence is implemented on the basis of the actualization and formation of typical cognitive phenomena. These phenomena are considered systemically and multifunctionally, namely as relatively independent cognitive: types of interactions, stages, strategies, channels, ontologies. Within the conceptual and substantive framework of this concept, we distinguish the following types of cognition (channels, strategies, etc.): I – orientational-cognitive; II – subject-cognitive; III – communicative and cognitive; IV – cognitive and analytical; V – cognitive and hermeneutic; VI – cognitive-ontological; VII – cognitive and creative. The identification of the indicated types of cognitive interactions is aimed at its representation as a complex, dynamic, multidimensional, multichannel intellectual system, the features of which are significant for educational and sociocultural practices, as well as for further development of artificial intelligence technologies, including its functional orientation and specificity, ergonomics, architecture, design and features of the interface. A study was conducted among students of higher education institutions aimed at determining the cognitive specificity (structure) of interaction in the “Human – Artificial Intelligence” system. Based on the analysis of the results of the distribution of answers for each of the test questions and the interpretation of the results of the cluster analysis (the Canopy algorithm was used), the dominance of the “I – orientational-cognitive” type of interactions was determined, which indicates a rather significant but initial interest in artificial intelligence technologies. There is also a relatively even distribution of all other types of cognitive interactions. The above reveals the novelty and innovation of artificial intelligence technology. This correlates with the respondents having developed different types of cognition, namely: orientational, analytical-synthetic, conceptual, interpretive, ontological, creative thinking, and corresponding intellectual intentions and motivation to use artificial intelligence tools in various spheres of activity.



1. Introduction

The rapid appearance in recent years of qualitatively new technologies of artificial intelligence [1,2], in relation to the well-established tradition of using computers and gadgets, contributes to the development of an appropriate culture of interaction in the “Human – Artificial Intelligence” system, which includes, first of all, the actualization and transformation of the cognitive component. The indicated problem has its significant and practically oriented projection into pedagogical practices as those that actively prescribe and apply new technologies of artificial intelligence. At the same time, methodological understanding of the cognitive aspects of interaction in the “Human – Artificial Intelligence” system, taking into account empirical data, is insufficient in pedagogical theory. The leading cognitive character of the interaction in the “Human – Artificial Intelligence” system determines the need for a detailed, specified, and practically oriented study of the intellectual dimension of the specified interaction.

The use of artificial intelligence in the educational process is considered an innovative digital technology that has the potential to reveal significant educational prospects and can qualitatively determine new educational and corresponding cognitive and creative effects. A relevant aspect of this problem is its consideration in the system of the competency paradigm, namely in the practical perspective of the formation and development of professional and key competencies of teachers of various specialties.

2. Analysis of current research

On the issue of artificial intelligence, the publications that were placed in the scientometric database Scopus from 2019 to April 2024 were analyzed. Figure 1 presents a thematic map of the connections of the elements (key topics) of the clusters formed by the request in the “Human – Artificial Intelligence interaction” in the Scopus scientometric database Scopus. Thematic research areas were grouped into five clusters in the VOSviewer system (table 1).

In Cluster 1, the following significant directions can be highlighted: human-computer interaction, cognitive computing, wareness, augmented reality, virtual reality, deep learning, user experience, future, prediction, medicine, diagnostics, health care, etc. Summarizing the direction of research in this cluster, it can be noted that they integratively reflect the issues of intellectualization, anticipation, psychologization, health preservation, the anthropological nature of man and his interaction with the computer. This cluster can be symbolically defined as “anthropological-psychological-anticipatory”, which represents a system of anthropologically, psychologically and practically oriented directions of interaction between humans and artificial intelligence, preservation of health, which can be the basis for future research.

Cluster 2 presents the following problem areas as relevant: AI agent, autonomous system, brain, cognitive science, computer science, human-robot interaction, learning, neurology, social interaction, etc. Summarizing the directions of research in this cluster, it can be noted that they integratively reflect the issues of intellectualization, neuronal and social nature of man, his interaction with the computer, and his interaction with the Artificial Intelligence. This cluster can be symbolically defined as “neuro-cognitive-social”, which represents a system of cognitively, neuro-, and socially oriented directions of human-artificial intelligence interaction.

Cluster 3 presents such problem areas as relevant, such as: cognitive load, natural language process, conversation, education, game, natural language process, training, Internet, virtual agent, etc. Summarizing the directions of research in this cluster, it can be noted that they integratively reflect the issues of communication, learning, and the game dimension of human nature and its interaction with the computer. This cluster can be symbolically defined as “communicative-linguistic-cognitive-game”, which represents a system of communicative, linguistically oriented directions of interaction between humans and artificial intelligence.

Cluster 4 presents such problem areas as relevant, such as: cognitive psychology, explainable AI, conversational agent, mental model, motivation, trust, etc. Summarizing the directions

Table 1. The cluster model of connections of research areas of scientists on the topic “Interaction in the “Human – Artificial Intelligence” system” from 2019 to April 2024, developed using data from the Scopus [4] abstracts and citations database.

Cluster number	Cluster content
Cluster 1	accuracy, assessment, augmented reality, automation, classification, cognitive computing, computer, dataset, deep learning, device, diagnosis, disease, engineering, future, health care, human, human-computer interaction, human factor, image, medicine, nurse, patient, prediction, recognition, safety, situation, wareness, software, thing, treatment, user experience, virtual reality
Cluster 2	agent, AI agent, architecture, artificial agent, aspect, autonomous system, autonomy, body, brain, case, study, cognitive architecture, cognitive function, cognitive model, cognitive science, cognitive system, computer science, emotion, evolution, hand, human brain, human intelligence, human robot interactor, intelligence, intention, learning, mechanism, mind, neuroscience, pattern, robot, robotic, social, interaction, social robot
Cluster 3	cognitive load, condition, content, conversation, covid, education, effectiveness, efficacy experience, feedback, game, group idea, improvement, natural language process, participant recommendation, speech student, teacher, text, training, usability, video, virtual agent, voice, web
Cluster 4	cognitive psychology, conversational agent, discipline, effect, explainable AI, explanation, factor, mental model, motivation, outcome, relation, review, risk, team, theory, trust
Cluster 5	decision, decision maker, decision making, experiment, impact, individual, information, machine, need, person quality requirement, situation

of research in this cluster, it can be noted that they integratively reflect the issues of communication, modeling, motivational aspects of human nature and its interaction with the computer, etc. This cluster can be symbolically defined as “communicative-modeling-motivational”.

Cluster 5 presents such problem areas as relevant, such as: decision-making, information, need, person quality requirement, etc. Summarizing the directions of research in this cluster, it can be symbolically defined as “informational and operational”.

Considering the integrative directions of research reflected in these clusters, we can schematically distinguish the main “meta-directions” of research: anthropological, cognitive, psychological, anticipatory neuronal, social, communicative-linguistic, game, information, and modeling.

Currently, the application of artificial intelligence in education is relevant in the development and application of training programs for school teachers. The work of Zhang et al. [5] is devoted to the study of the indicated problems. The authors analyze the determinants of teachers’ behavior that contribute to the use of artificial intelligence.

Chen et al. [6] used bidirectional long-term memory (Bi-LSTM) and convolutional neural network (ConvNet/CNN) models to build a classroom learning quality assessment model. Neural networks were used to assess the quality of language teaching in secondary schools. The authors used simulation studies and comparative analysis. Bidirectional long-term memory (Bi-LSTM)

creating a system of a virtual intelligent teacher's assistant that interacts through voice. The specified system can answer actual questions about training courses.

Chan [13] researched the educational policy of using artificial intelligence in higher education. The author analyzes the perception of artificial intelligence technologies capable of generating texts. He proposes a framework policy for environmental education of artificial intelligence with the aim of introducing it into the educational process of universities, including teaching and learning. The researcher's system included the analysis of three dimensions – pedagogical, managerial and operational.

Ahmad et al. [14] studied the influence of artificial intelligence on decision-making, the problem of laziness and confidentiality among university students in China and Pakistan. The authors indicate that artificial intelligence significantly affects decision-making and contributes to the development of laziness.

Investigating interaction in the “Human-Computer” system, Klochko et al. [15] integratively used the theory of movement construction and the Umwelt concept of Jakob Johann von Uexküll [16,17]. Interaction in the “Human-Computer” system is considered by the authors in a structured, systematic and spatial manner with the selection of certain levels. This includes the formation of an understanding of the interaction in the “Human-computer” system as multidimensional with the selection of not only cognitive, but also bodily, ontological, and spatial components, can be purposefully applied to increase the effectiveness of this interaction. This study, which is based on the application of the theory of the step-by-step formation of mental actions, is a further development of the above, formed on the basis of the use of the theory of building movements and the concept of Umwelt.

In the scientific pedagogical literature, the problem of the cognitive specificity of the interaction in the system “Human – Artificial Intelligence” in the context of the development of professional and key competences of teachers is not sufficiently disclosed. The cognitive aspects of the application of artificial intelligence for the professional training of future teachers of mathematics and computer science have not been sufficiently considered.

The purpose of the study is to conduct an analysis of the cognitive specificity of the interaction in the “Human – Artificial Intelligence” system in the context of professionalization of future teachers of mathematics and computer science, specialists in the field of information technology.

3. Selection of methods and diagnostics

Own methodological developments. Based on the analysis of previously conducted targeted communication, observation and survey of future teachers of mathematics and computer science, we examined the interaction in the “Human – Artificial Intelligence” system with the selection of typical cognitive effects, which in the majority of cases can be presented in the format of a certain sequence or phrasing. The indicated effects of cognitive interaction in the “Human – Artificial Intelligence” system were conceptualized and accordingly represented as specific cognitive phenomena. Thus, we distinguish the following cognitive phenomena: “orientational-cognitive”, “subject-cognitive”, “communicative and cognitive”, “cognitive and analytical”, “cognitive and hermeneutic”, “cognitive-ontological”, “cognitive and creative”. The specified sequence to some extent reflects the stages of their occurrence.

Based on the selection of the specified cognitive phenomena that occur during interaction in the Human-Artificial Intelligence system, we developed questions integrated into the Fedorets-Klochko test “Analysis of the cognitive specificity of interaction in the Human-Artificial Intelligence system”.

- 1 To what extent are you familiar with artificial intelligence technologies?
- 2 Do you have a desire to use artificial intelligence technologies?
- 3 Do you use artificial intelligence systems for fun and games?

- 4 Do you use artificial intelligence systems to solve your private issues?
- 5 Do you use artificial intelligence technologies to solve the tasks of your future professional activity?
- 6 Do you use artificial intelligence technologies to solve issues related to appearance?
- 7 Do you use artificial intelligence technologies to solve housing design issues?
- 8 Do you use artificial intelligence technologies to find everyday things, works of art, natural artifacts, landscapes, etc.?
- 9 Do you use artificial intelligence technologies to solve your own health issues?
- 10 Do you use artificial intelligence technologies to solve psychological issues?
- 11 Do you use artificial intelligence technologies to solve pedagogical issues of future professional activity?
- 12 Do you use artificial intelligence technologies to solve the problems of finding and forming texts, images and scenarios necessary for future professional and educational activities?
- 13 Do you use artificial intelligence technologies to solve personal communication issues?
- 14 Do you use artificial intelligence technologies to solve intellectual issues of future professional activity, in particular, decision-making?
- 15 Do you use artificial intelligence technologies to solve intellectual personal issues, in particular, decision-making?
- 16 Do you use artificial intelligence technologies to interpret data, events, phenomena, processes, etc.?
- 17 Do you use artificial intelligence technologies to deepen understanding of the contents and meanings of future professional activities and personally significant events, images, data, etc.?
- 18 Do you use artificial intelligence technologies to analyze different interpretation options for certain data, events, phenomena, processes and decision-making?
- 19 Do you use artificial intelligence technologies to plan and predict certain events in order to avoid risks?
- 20 Do you use artificial intelligence technologies to improve the level of your educational achievements and life creativity, including making important life decisions?
- 21 Do you use artificial intelligence technologies for professional and creative development?
- 22 Do you use artificial intelligence technologies as a hobby?

Answer options for the test questions: “No”, “Yes to a lesser extent”, “Yes to a greater extent”.

In this test, certain questions reflect the manifestation of the above-mentioned cognitive phenomena that are formed in the process of interaction in the “Human – Artificial Intelligence” system. Let’s present the specified connections between the test questions and the cognitive phenomena we selected.

Cognitive phenomena:

- orientational-cognitive – 1-4;
- subject-cognitive – 5-12;
- communicative and cognitive – 13-14;
- cognitive and analytical – 15-16;
- cognitive and hermeneutic – 17-19;
- cognitive-ontological – 20-21;

- cognitive and creative – 22.

In the research, we used system analysis, cluster analysis, data visualization, etc. The Canopy algorithm was used for data clustering [18, 19], which is also used for preliminary data clustering [7, 20–23]. We determined the optimal number of clusters in the data set representing the test results using Hubert’s index, Ward’s minimum variance method (Ward D and Ward D2) [24, 25]. According to the results of preprocessing of the data, it was determined that the optimal number of clusters is 4 clusters.

We implemented cluster data analysis using the Weka platform [26].

4. Results and discussion

According to the results of empirical observations and experimental studies conducted in the format of testing, the presence of certain cognitive phenomena that are formed as a result of the interaction of humans and artificial intelligence has been determined. The specified cognitive phenomena can be considered both arbitrarily existing and relatively independent of each other, and as successive stages of development of typical transformations of the human cognitive sphere with relatively constant interaction with artificial intelligence. We consider the specified cognitive changes, which are formed as a result of the interaction between a person and artificial intelligence, in the format of the “Concept of cognitive multi-channel Human-Computer interaction” developed by us. The essence of this concept is that the interaction of the cognitive sphere of human and artificial intelligence is realized on the basis of the actualization and formation of typical cognitive phenomena, which are considered systemically and multifunctionally, namely as relatively independent intellectual strategies that exist in parallel, and in the temporal aspect are considered as certain stages of transformation of the cognitive sphere. These understandings are correlated with neurophysiological ideas about the simultaneous processing of information by the brain, which is manifested as simultaneous and successive neuronal processes, which are sequential. Thus, multi-channel is realized both in time due to phasing, within which in certain periods the dominance of certain channels of information and their sequential change is present, and in space when all channels are used to a large extent, which also includes the possibility of advantages of some of them, in particular, strategies, images, contexts, representations, schemes, ideas.

Cognitive phenomena are represented as those formed at certain stages of ontogenesis (individual development), and in adulthood they represent cognitive-functional formations, that is, as certain types of thinking and cognitive strategies. In addition to the step-by-step understanding (that is, as typical stages of the formation of the cognitive sphere) of the specified cognitive phenomena in the content-semantic framework of the “Concept of cognitive multi-channel Human-Computer interaction”, the human cognitive sphere is structured from the selection of the sum of cognitive systems (more precisely, subsystems). The specified cognitive systems, depending on their manifestations, can be presented in different formats (figure 2) as:

- cognitive types of interactions in the “Human-Artificial Intelligence” system;
- cognitive strategies and tools of intellectual activity;
- cognitive channels of interaction with artificial intelligence;
- cognitive ontologies in which artificial intelligence is included as a component.

The analysis of the cognitive specificity of the interaction in the “Human – Artificial Intelligence” system can be carried out axiomatically and, accordingly, arbitrarily with the selection of aspects significant for certain purposes and systems that are considered as cognitive. At the same time, in this version of consideration of the specifics of human interaction and artificial intelligence, we use established scientific teachings, namely the methodological potential

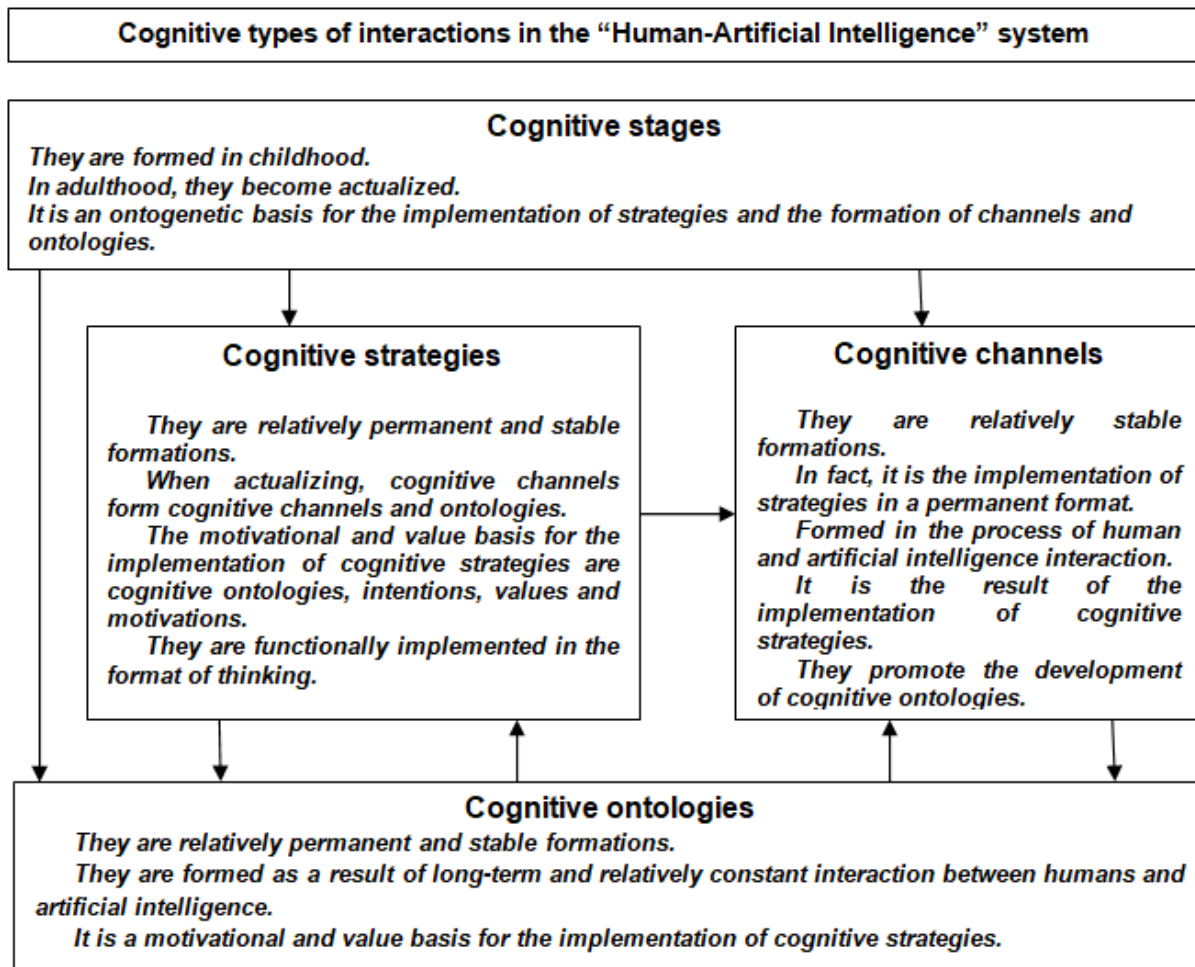


Figure 2. Cognitive phenomena (cognitive types of interactions) that are formed as a result of the interaction of human and artificial intelligence and which, depending on their functional understanding, are represented in different formats – cognitive channels, strategies, ontologies.

of the theory of the step-by-step formation of mental actions, Piaget’s operational theory of intelligence, and the theory of functional systems.

In accordance with the pedagogical orientation of research within the framework of this concept, we distinguish the following stages (which are simultaneously considered as cognitive strategies (tools), ontologies, channels):

- I – orientational-cognitive;
- II – subject-cognitive;
- III – communicative and cognitive;
- IV – cognitive and analytical;
- V – cognitive and hermeneutic;
- VI – cognitive-ontological;
- VII – cognitive and creative.

The next aspect of this concept is the idea that the consideration and representation of cognitive systems in different formats has a purely practical meaning and is connected with the

idea of transformations that can occur in the cognitive sphere. A similar approach was applied by Piaget [27], which includes the actualization of the idea of transformations that occur in the cognitive sphere of a person in the process of his intellectual development and are aimed at adaptation to the environment, including the objectification of the cognitive reflection of reality.

Based on the regularities of the formation of functional systems, we can express the idea that the indicated interactions in the human-artificial intelligence system will also have a certain stage of development. Initially, cognitive channels of interaction with artificial intelligence will be formed, then typical cognitive strategies will be developed as tools of intellectual activity, which from a psychophysiological point of view represent functional systems. Next comes the “rootedness” of the specified strategies in the human being, their ontologization and correspondingly developing cognitive ontologies, in which artificial intelligence is included as a component. Schematically, it can be represented as a sequence: stage of interaction – channel of interaction – cognitive strategies – cognitive ontologies. At the same time, when it is formed, they will exist and interact relatively independently and autonomously, while actualizing potentials, which to some extent includes the possibility of transition from one format to another, but in general they will function integratively as a whole. The manifestation or dominance of a certain cognitive quality of a strategy, ontology or channel will depend on requests and needs.

Let’s consider the cognitive phenomena highlighted above as relevant in the interaction of humans and artificial intelligence.

As indicated above, I is an orientational-cognitive phenomenon, which is considered at the same time as a stage, channel, strategy and ontology, which determines the orientation and orientation in the specified interaction. This cognitive phenomenon is a defining generality in the intellectual sphere of a person and is presented in such a way that in ontogenesis (individual development) it is formed primarily on the basis of an orientation-searching reflex, which is defined as an innate human quality that develops into orientation-searching behavior, which, in turn, becomes the basis for orienting intelligence and intelligence as such in general. The main biological and salutary meaning of orienting-searching behavior is the identification of probable threats and the determination of ways to provide vital needs in food, communication, housing, etc. Orientation in oneself and in the environment is a system-organizing phenomenon of all mental activity, which can be disturbed in case of a certain mental pathology. The development of orienting intelligence, which includes the ability to effectively navigate life and professional problems, is a significant factor in the harmonious existence of a person and his successful activity. In accordance with the vital and cognitive meaning of orientation and orientation-research behavior, we actualize the orientation-cognitive dimension of human-artificial intelligence interaction, which, as noted above, is considered at the same time as a stage, channel, strategy, and ontology. Accordingly, the primary is the orientational-cognitive stage, which determines the development of the corresponding channel of interaction. For the implementation of the orientational-cognitive stage, which determines the development of the orientational-cognitive channel of interaction, vital and cognitive intentions and motivations related to both professional activity and life creativity of a person are relevant. Orientation-cognitive strategies are formed on the basis of the development of the specified channel and, accordingly, determine the possibility of the formation of the ontology of the same name. At the same time, the formed orientational-cognitive ontology in turn becomes a powerful “orientational-search-motivational-cognitive context” in the implementation of the specified strategies and maintenance of the appropriate channel of interaction.

II – the subject-cognitive stage, which is aimed at specific subjects in an adult, and to a large extent extends to various life and professional spheres and interests. In ontogenesis, it is formed on the basis of subject-manipulative activity and determines the development of the sphere of praxis, which includes speech praxis. The specified subject-cognitive channel of interaction develops on the basis of the implementation of the previous orientational-cognitive. Activity

strategies and, to a lesser extent, ontology are decisive in subject-cognitive interaction in the “human-artificial intelligence” system. That is, this stage is essentially an activity stage. This is due to the manipulative and active nature of this level, which is focused on a specific activity and result. This format of interaction is connected with images, mental and cognitive maps of objects and with activities that to some extent relate to the subject or wider material sphere.

III – communicative and cognitive stage, which actualizes the transformation and interaction of semiotic-symbolic systems and is manifested in speech, communication, including dialogic. It is formed on the basis of the previous two stages presented above (I and II), and in an adult it is largely relatively autonomous from them. This stage is essentially “communicative” and “communicative and cognitive”, which determines the formation of appropriate interaction strategies in the “Human – Artificial Intelligence” system. No less significant is the development of the corresponding communicative and cognitive ontology, which is based on the semiotic-symbolic sphere of speech and communication. This format of “Human – Artificial Intelligence” interaction is related to signs, symbols and communication. That is, this interaction is mediated through a sign, symbol, symbol-image and dialogue. This channel is the main and defining one in the interaction in the “Human – Artificial Intelligence” system.

IV – cognitive and analytical stage, manifested, first of all, in operational thinking as a special mental activity formed on verbal and verbal-logical bases. That is, it is formed on the basis of the 3rd communicative and cognitive stage. Accordingly, this stage has multiple manifestations, but, above all, it is represented by analytical-synthetic and conceptual cognitive processes, that is, thinking in its “authentic” format. The cognitive and analytical interaction between human and artificial intelligence determines the formation and dominance of the corresponding strategy and ontology. These are the cognitive and analytical stage.

In the system of this cognitive and analytical interaction, the V cognitive-interpretive (cognitive and hermeneutic) type (stage) of interaction is significant, which can also be singled out as a separate saliently significant strategy (we do not consider it in detail in this study) and to a lesser extent ontology.

VI – cognitive-ontological stage (interaction) is manifested in the format of cognitive and metacognitive processes in which cognitive-ontological are integrated. This is the cognitive-ontological basis for the development of cognitive ontologies, images, scenarios, and also contributes to anticipation, planning, forecasting. The idea of thinking as an ontology largely corresponds to the Cartesian maxim – *Cogito ergo sum* (Latin)

VII – cognitive and creative stage (interaction), is manifested in creative thinking, which includes actualization of intuition, integrative application of cognitive, metacognitive interpretive strategies, context, as well as actualization of cognitive practices in real time. This type of interaction in the “Human – Artificial Intelligence” system is not something that corresponds to the logic of the development of the cognitive sphere and, accordingly, is not considered as a transformation of the previous ones. It is relatively autonomous and can be inherent in any of the methods of interaction presented above. At the same time, the probability and expressiveness of this method of interaction will increase as the stages presented above unfold.

The concept of interaction between humans and artificial intelligence presented by us is a targeted interpretation of the theory of the step-by-step formation of mental actions. From the standpoint of this theory, thinking in ontogenesis is formed as a process that is initially developed in the external environment. Accordingly, thinking is formed through the actualization of such stages as: motivation and orientation; substantive or material actions; external (expressive) language; internal (impressive) language; mental actions. Based on the application of the theory of functional systems and observation of reality, we can note that each of the presented stages, which represents a specific type of interaction with the environment in an adult, also functions as a specific function, as a tool. Accordingly, the same will be manifested in the interaction of humans and artificial intelligence.

In 2023, research was conducted among students in 3 higher education institutions of Ukraine. For this, the Fedorets-Klochko test “Analysis of the cognitive specificity of the interaction in the Human-Artificial Intelligence system” was used. Research was conducted at: Vinnytsia Humanitarian and Pedagogical College, Mykhailo Kotsiubynskyi State Pedagogical University, Vinnytsia Academy of Continuing Education, Berdyansk State Pedagogical University, Dragomanov Ukrainian State University. 142 respondents (students) took part in the study. The purpose of the study was to determine the cognitive specificity of interaction in the “Human – Artificial Intelligence” system. The test results were processed using cluster analysis. Four clusters were formed (table 2, table 3).

As a result of testing students using the Fedorets-Klochko test “Analysis of the cognitive specificity of interaction in the Human-Artificial Intelligence system”, we obtained the data set

Table 2. A cluster model for determining groups of students by type of interaction in the “Human – Artificial Intelligence” system, built using the Canopy algorithm.

Question number	Cluster 0	Cluster 1	Cluster 2	Cluster 3
Q1	2	1	1	1
Q2	2	0	1	1
Q3	1	0	0	1
Q4	1	0	1	1
Q5	1	0	1	1
Q6	0	0	0	1
Q7	0	0	0	1
Q8	0	0	0	1
Q9	0	0	0	1
Q10	0	0	0	1
Q11	1	0	0	1
Q12	1	0	1	1
Q13	0	0	0	1
Q14	0	0	0	1
Q15	0	0	0	1
Q16	1	0	0	1
Q17	0	0	0	1
Q18	0	0	0	1
Q19	0	0	0	1
Q20	0	0	1	1
Q21	1	0	1	1
Q22	0	0	1	1

Table 3. The cluster model for determining groups of students by type of interaction in the “Human – Artificial Intelligence” system, built using the Canopy algorithm.

Cluster number	Volume of cluster
0	55 (39%)
1	37 (26%)
2	24 (17%)
3	26 (18%)

shown in figure 3. For the purpose of data processing using the Canopy algorithm, the values of the test results are replaced accordingly: “No” by 0, “Yes to a lesser extent” by 1, “Yes to a greater extent” by 2 (figure 3). Question 1, Question 2, ... , Question 10 is marked as Q1, Q2, ..., Q10 respectively (table 2).

```
@DATA
1,2,1,1,1,1,0,1,0,0,1,1,0,1,1,1,1,0,1,1,0
2,2,0,1,2,0,0,1,0,0,1,2,0,1,0,2,2,2,2,2,0
2,2,0,2,2,0,0,1,0,0,1,1,0,0,0,1,2,1,0,1,2,0
2,2,2,2,1,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,1,2
1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,1,0,0,0,0
2,2,1,2,1,0,0,0,0,0,1,2,0,0,0,1,1,1,0,1,1,1
1,1,0,0,1,0,1,0,0,0,1,0,0,0,0,0,0,0,0,0,1,0
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Figure 3. Data set of testing students using the Fedorets-Klochko test “Analysis of the cognitive specificity of interaction in the Human-Artificial Intelligence system”.

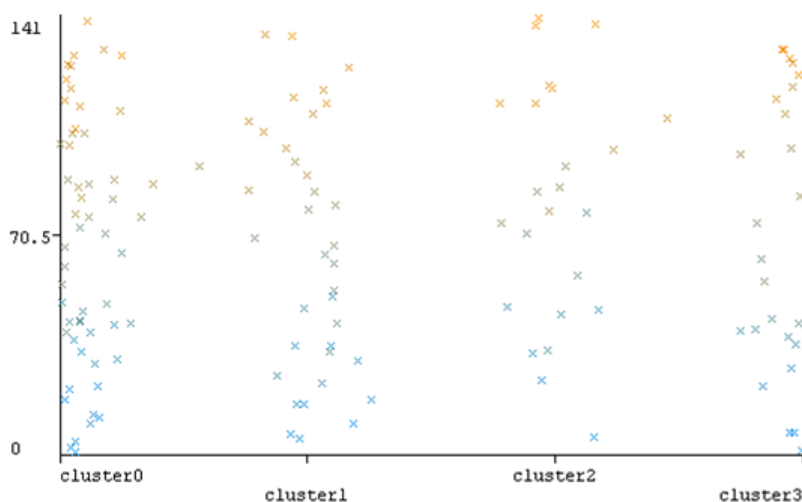


Figure 4. Graphic presentation of the clusters of the distribution of students by type of interaction in the “Human – Artificial Intelligence” system, built using the Canopy algorithm.

Cluster 0, which is formed by 39% of students, is mainly represented by mixed positive and negative answers. Positive answers are given to questions № 1, № 2, № 3, № 4, which indicates the actualization of the orientational-cognitive type of interaction (table 2, table 3, figure 4). Positive answers to questions № 5, № 11, № 12 indicate a slight manifestation of the subject-cognitive type of interaction. Positive answers to question № 21 show the actualization of the cognitive-ontological type of interaction. That is, in this cluster, the orienting-cognitive type of interaction is fully actualized. Other types of interactions are slightly updated: subject-cognitive and cognitive-ontological. This indicates the presence of interest in learning with the use of artificial intelligence and, at the same time, insufficient familiarity with it, which speaks of further prospects for the introduction of this technology. The dominant number of 39% demonstrates the progressive and active nature of the implementation of this technology and significant interest in its use.

Cluster 1, which is formed by 26% of students, is dominated by mostly negative answers (table 2, table 3, figure 4). In this cluster, only the answer to question № 1 is positive. The

indicated structure indicates a lack of knowledge about artificial intelligence technology in its practical formats.

Cluster 2, formed by 17% of respondents, is dominated by mostly negative answers (table 2, table 3, figure 4). For this type of respondents, the presence of some positive answers is relevant, which characterize a slight update of the orientational-cognitive level, which indicates an interest in this technology.

Cluster 3, which accounts for 18% of responses, is represented by positive responses in all questions, indicating a certain initial level of application of artificial intelligence technology (table 2, table 3, figure 4).

We will analyze the students' answers to each question separately (figure 5). The structure of answers to the first four questions, among which, compared to other questions, the most positive answers indicate the actualization of the orientational-cognitive type of interaction in the "Human – Artificial Intelligence" system. Such dominance of four issues as the type of interaction itself also indicates the presence of a primary interest in artificial intelligence as a new cognitive and educational technology, which is manifested in the actualization of orienting intelligence, as well as in its rather active focus on the specified digital technology. It also indicates the novelty of artificial intelligence technologies, which correlates with a correspondingly significant interest in it.

The presence of a small number of positive answers in questions 5-12 indicates the activity correlated with these answers, which includes the actualization of the subject-cognitive type of interactions that appears in the real application of artificial intelligence as technologies, both in everyday life and for solving personal and professional problems (figure 5).

The dominance of negative answers against the background of a small number of positive ones in questions 13-14 indicates the minimum and initial level of communicative and cognitive interaction in the "Human – Artificial Intelligence" system. Accordingly, the speech and dialogic aspects of the indicated interaction are insufficiently demonstrated (figure 5).

The predominance of negative answers in the presence of a fairly insignificant number of positive ones in questions 15-16 characterizes the initial and rather insignificant manifestation of the cognitive and analytical type of interaction in the "Human – Artificial Intelligence" system (figure 5). That is, in the field of thinking and, accordingly, in all its variety of manifestations, artificial intelligence occupies an insignificant marginal position.

Questions 17-19 reflect the cognitive and hermeneutic (cognitive and interpretative) type of interaction (figure 5). They have a similar structure of answers to the one inherent in the questions in which the cognitive and analytical type of interaction is represented (questions 15, 16). At the same time, in questions 17-19, compared to 15, 16, there are more positive answers, which indicates an interest in artificial intelligence, which is manifested in the actualization of interpretive intelligence and attempts to understand and reveal for oneself the essence and practice of the specified digital technology.

Answers to questions 20 and 21, which reflect the cognitive-ontological type of interaction in the "Human – Artificial Intelligence" system, have a close structure of answers that are characteristic of the cognitive and analytical and cognitive and hermeneutic type of interactions (figure 5). This indicates that the cognitive-ontological level, which is to some extent dependent and derived from cognitive and analytical, is not formed.

The structure of the answers to question 22, which reflects the cognitive-creative type of interaction, is generally quite similar to the answers to the questions that characterize the previous three levels – cognitive and analytical, cognitive and interpretative, cognitive-ontological (figure 5). This indicates an initial, initial and, in general, insufficiently actualized, cognitive and creative type of interaction. This distribution of answers with a predominance of negative ones also indicates the lack of sufficient "inclusion" of artificial intelligence technologies in both creative and cognitive activities, which are aimed at the manifestation of novelty.

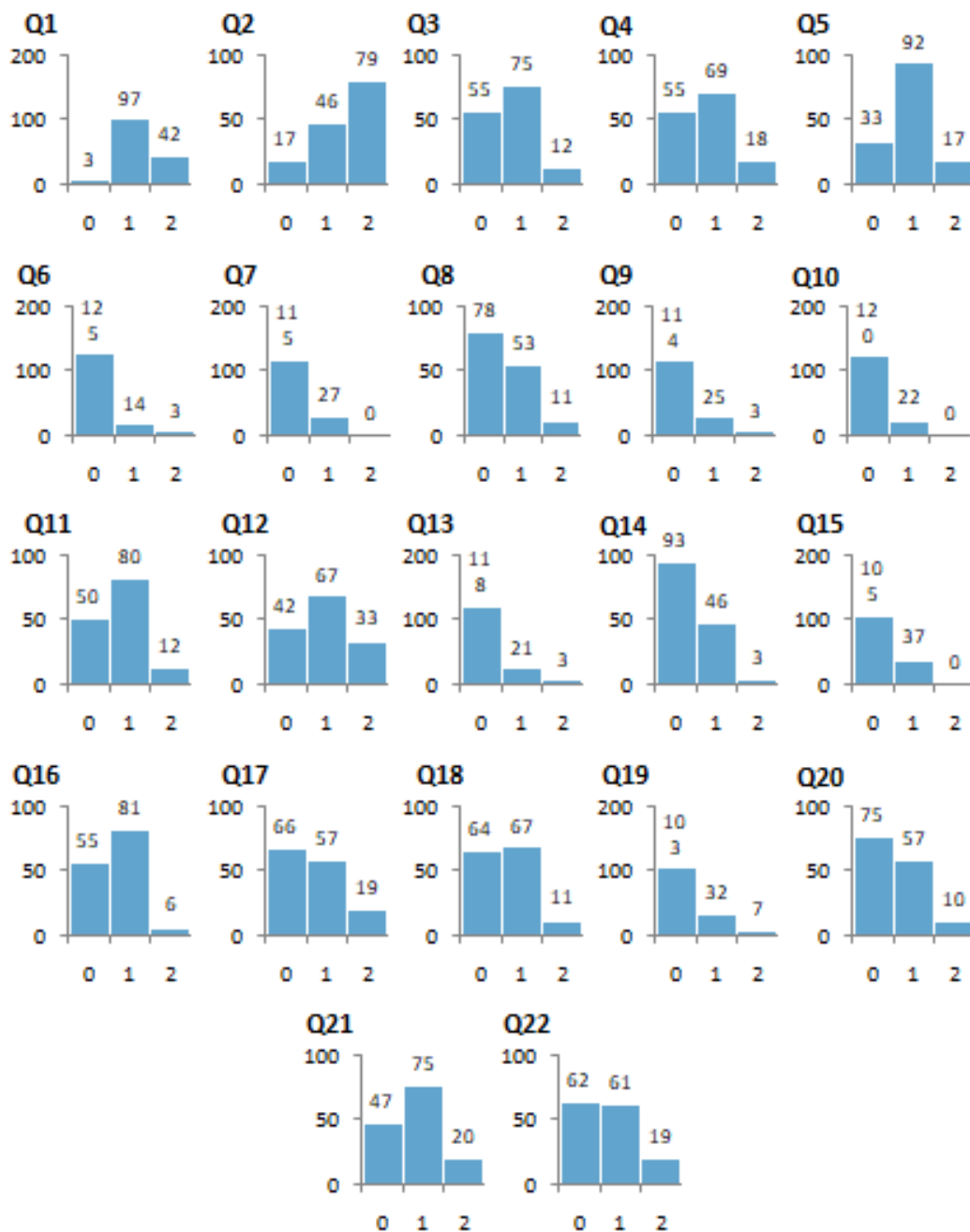


Figure 5. Graphic representation of the distribution of students’ answers to the questions of the Fedorets-Klochko test “Analysis of the cognitive specificity of interaction in the Human-Artificial Intelligence system”.

5. Conclusion

The disclosure of the phenomenology of cognitive transformations and interactions in the “Human – Artificial Intelligence” system was carried out on the basis of the “Concept of cognitive multi-channel Human-Computer interaction” developed by us (Fedorets-Klochko). In the system of this concept, the specified interaction is considered as a manifestation and formation of typical cognitive phenomena that manifest both sequentially in time and simultaneously, which includes

competitive and synergistic interactions. Depending on the functionally oriented understanding, the specified cognitive phenomena are considered multidimensionally as cognitive: types of interactions, stages, channels of interactions, strategies, ontologies.

Within the conceptual and substantive framework of the specified concept, we distinguish the following types of cognition (channels, strategies, etc.): I – orientational-cognitive; II – subject-cognitive; III – communicative and cognitive; IV – cognitive and analytical; V – cognitive and hermeneutic; VI – cognitive-ontological; VII – cognitive and creative.

The identification of the specified types of cognitive interaction is aimed at its representation as a complex, dynamic, multidimensional, multichannel intellectual system, the features of which are significant for educational and sociocultural practices, as well as for further development of artificial intelligence technologies, including its functional orientation and specificity, ergonomics, architecture, design and features of the interface.

Studies of students and teachers of higher educational institutions were conducted aimed at determining the cognitive specificity (structure) of interaction in the “Human – Artificial Intelligence” system. For this, we used the Fedorets-Klochko test “Analysis of the cognitive specificity of interaction in the system “Human – Artificial Intelligence” and cluster analysis. Four clusters were identified, which characterize the specifics of this interaction. Cluster 0 (table 2, table 3), formed by 39% of students, reflects the progressive and innovative nature of the implementation of artificial intelligence technology and the presence of significant interest in its use. This cluster largely reflects the actualization of the oriented-cognitive type of interaction, and to a lesser extent the subject-cognitive, cognitive-ontological. Cluster 1, which is formed by 26% of students, indicates a lack of knowledge about the practical application of artificial intelligence technologies.

Cluster 2 (table 2, table 3), which is formed by 17% of the respondents, indicates a slight update of the indicative cognitive level. Cluster 3 (table 2, table 3), formed by 18% of responses, indicates a certain initial level of application of artificial intelligence technologies. This cluster reflects the specificity of the actualization of the subject-cognitive type of interactions in the “Human – Artificial Intelligence” system, as well as the initial level of manifestation of communicative-cognitive, cognitive-analytic, cognitive-hermeneutic, and cognitive-ontological types of interactions in the “Human – Artificial Intelligence” system “Artificial Intelligence”. Based on the analysis of the results of the distribution of answers for each of the test questions and the interpretation of the cluster analysis, the dominance of the “I – orientational-cognitive” type of interactions was determined, which indicates a significant but initial interest in artificial intelligence technologies.

The relatively even distribution of all other types of cognitive interactions in Cluster 3 (18%) (table 2, table 3) indicates a significant interest in artificial intelligence technologies. It also indicates that, subject to its application, there is a certain initial intellectual level of actualization in all other defined types of interactions. The use of AI technologies in educational and professional activities and life creation contributes to the professionalization and intellectualization of future teachers of mathematics and informatics, specialists in the field of information technologies. The above also represents the novelty of artificial intelligence technology, which is relative to the primary and sufficiently developed in the researched different types of cognition, including orienting, analytical-synthetic, conceptual, interpretive, ontological, creative thinking and the corresponding intellectual intentions and motivations for its use.

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Nanoart in STEAM education: Combining the microscopic and the creative

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Abstract. This article explores the integration of Nanoart within the STEAM (Science, Technology, Engineering, Art, and Mathematics) education framework, highlighting its pivotal role in enhancing interdisciplinary learning. Through a detailed examination of a project-based learning (PBL) initiative, the study showcases students specializing in “Applied Physics and Nanomaterials” engaging in creating nanostructures via electrochemical etching and their subsequent transformation into Nanoart. This educational endeavor exemplifies the seamless integration of STEAM components—combining scientific principles, technological application, engineering design, artistic creativity, and mathematical precision—and significantly deepens students’ understanding of these elements. The article details each project phase, from conceptualization through execution, illustrating how students navigate the complexities of nanoscience and apply their interdisciplinary knowledge to produce tangible artistic and scientific outcomes. By transforming abstract scientific concepts into visually and intellectually stimulating Nanoart, the project encourages creative thinking and innovation among students. It further demonstrates how integrating art into STEM subjects can make scientific education more accessible and engaging, attracting a more comprehensive array of students and enriching their academic and practical experiences. Additionally, the study discusses the broader implications of Nanoart in STEAM education, emphasizing its effectiveness in bridging the gap between scientific exploration and artistic expression. It argues that this approach not only demystifies complex concepts but also fosters a holistic educational environment that prepares students to think critically and creatively across disciplines.

1. Introduction

Nanoart stands at the convergence of scientific innovation and artistic expression, representing a unique realm where materials are manipulated at the nanoscale to create visually striking and conceptually rich artworks [1, 2]. This emerging art form exemplifies the integration of art and science and serves as a means through which complex scientific ideas, especially those related to nanotechnologies, can be communicated and explored in an educational context [3].

Nanoart originated with technologies that allowed visualization and manipulation of matter at the nanoscale [4]. Pioneers in this field combined their nanotechnological expertise with artistic vision, creating works that challenge traditional notions of art and science [5]. These artworks range from images captured using electron microscopes, creatively colored and rendered, to structures created atom by atom using atomic force microscopy or scanning electron microscopy [6, 7].

The educational landscape has long emphasized the importance of STEM subjects (science, technology, engineering, and mathematics) as foundational pillars of modern education [8, 9].



However, integrating art into this framework, transforming STEM into STEAM, has gained significant momentum in recent years [10, 11]. This shift recognizes the value of creativity and critical thinking skills provided by artistic disciplines, enriching the learning experience and fostering a more holistic understanding of scientific concepts [12].

The concept of STEAM education emerged from recognizing that the skills and ways of thinking nurtured by the arts are an essential complement to those developed through STEM subjects [13]. This educational approach advocates for a more integrated and comprehensive curriculum, where creative thinking and artistic skills are viewed as crucial for innovation and problem-solving in scientific fields [14].

One of the challenges in contemporary education, especially within the STEAM paradigm, is making advanced and often abstract scientific concepts accessible and appealing to students [15]. Nanoart presents a unique opportunity to bridge this gap. By visualizing the invisible world of atoms and molecules, Nanoart captivates the imagination and deepens the understanding of nanoscience, a field at the forefront of technological advancement and innovation.

The conversion process of the mirror-perfect surface of the crystal into the picture in Nanoart's style has several main stages (table 1).

Table 1. Main painting stages of the picture in the style of Nanoart.

No.	Name	Key point
1.	To create Nano	to form the nanostructure (give roughness and unique morphology)
2.	To see Nano	to get an image of the nanostructure (micrograph)

In the evolving landscape of STEAM education, combining scientific experiments and artistic creativity presents a unique and enriching opportunity for learning. This case study focuses on a project undertaken by students specializing in “Applied Physics and Nanomaterials”, where they participate in creating nanostructures using the method of electrochemical etching. The project's primary goal is the seamless integration of the technical aspects of nanotechnologies with the imaginative realm of nanoart, providing a comprehensive educational experience.

At the heart of this initiative lies project-based learning and immersive education. Students are not mere spectators but active participants in the scientific process, from conceptualization to execution. This approach provides a tangible context for theoretical knowledge, allowing students to apply their learning in real-life scenarios. The ultimate aim is to transcend traditional boundaries between science and art, creating a vibrant learning environment that encourages innovation, creativity, and interdisciplinary collaboration.

2. Case study

2.1. How to create Nano?

There are many ways to obtain nanostructures. Some of them are highly complex and require modern technological equipment (such as ion bombardment and epitaxy) [16], while others are simpler to implement (SILAR, sol-gel methods) [17]. They can generally be divided into “top-down” and “bottom-up”. Combined methods are also gaining popularity [18] (figure 1a).

However, for synthesizing nanostructures in laboratory classes, more straightforward methods, such as electrochemical processing, are used [19] (figure 1b). This technology is interesting because it is simple, inexpensive, and does not require high-tech equipment. The critical moment is also relatively straightforward: a semiconductor with a completely smooth surface is placed in an acid solution, through which an electric current is passed (figure 1c). This technology is well known in school as electrolysis, with the difference that platinum and semiconductor plates are used as electrodes for forming nanostructures.

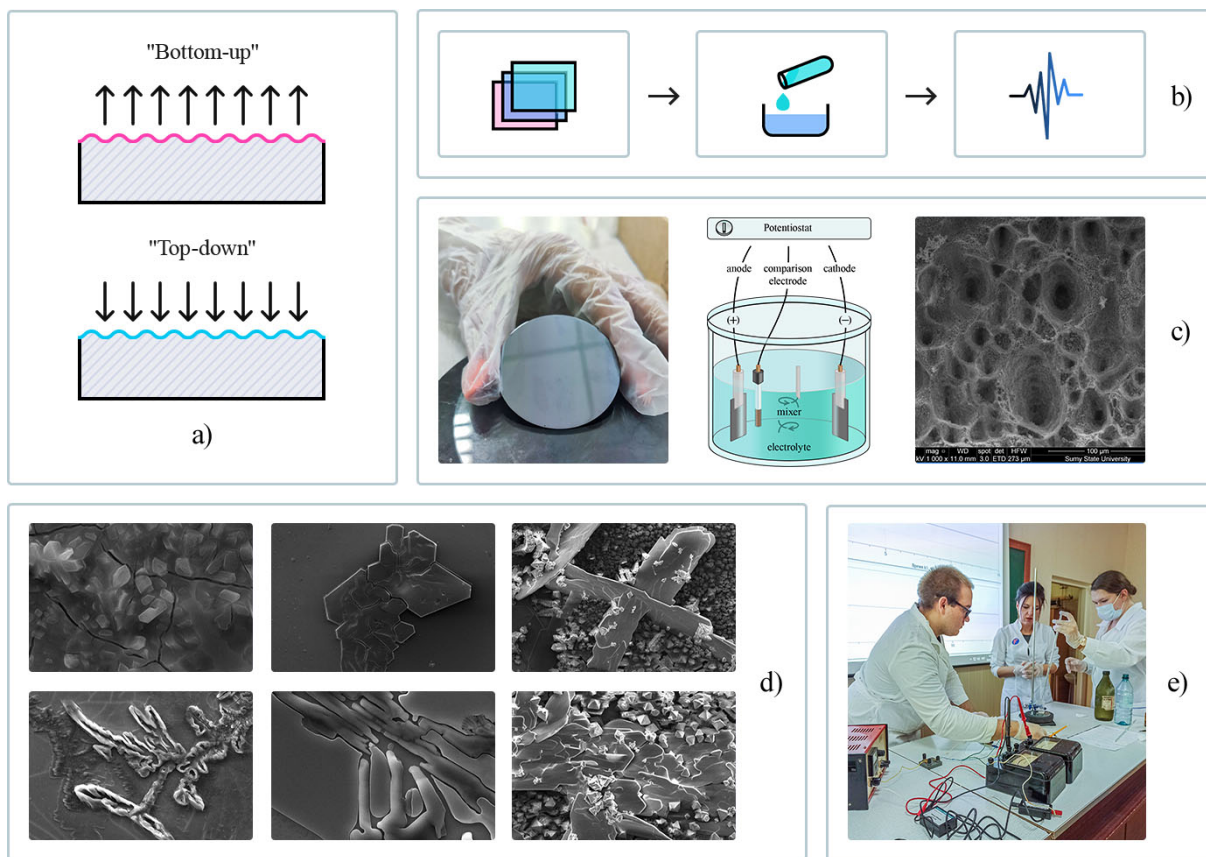


Figure 1. Nanomaterial synthesis: a) approaches to nanostructure synthesis; b) and c) scheme of electrochemical dissolution of crystal; d) examples of synthesized nanostructures; e) master-class “Chemistry? Alchemy? – No. Electrochemistry!”.

As a result, various types of nanostructures are formed on the surface: pores, crystallites, whiskers, wires, films, etc. A wide variety of obtained nanostructures can be achieved by changing the etching conditions and electrolyte composition. This means that after processing in acid solutions, an incredible nano relief of a smooth and mirror-perfect semiconductor surface is obtained (figure 1d).

It should also be noted that due to the simplicity of the method and the availability of electrochemical processing of the crystal, it can be used not only in scientific laboratories but also as a teaching method for students and schoolchildren. Figure 1e shows how students create nanostructures as part of the master class “Chemistry? Alchemy? – No. Electrochemistry!” It can be said that they are captivated by this. They feel like actual researchers, creators, and artists.

During the electrochemical processing of crystals, self-organization processes occur in the growth and dissolution of crystals. This means nanostructures are formed not spontaneously but according to a specific mechanism. This leads to truly incredible results. Thus, we obtained such structures as donuts, diamonds, desert roses, stone flowers, and more (figure 2).

2.2. How to see Nano?

A nanostructure is a collection of nanoscale objects whose properties are determined by the sizes of structural elements and their mutual arrangement in space. At least one area of the smallest element must have a size of less than 1 nm (one billionth of a meter). Consequently, it

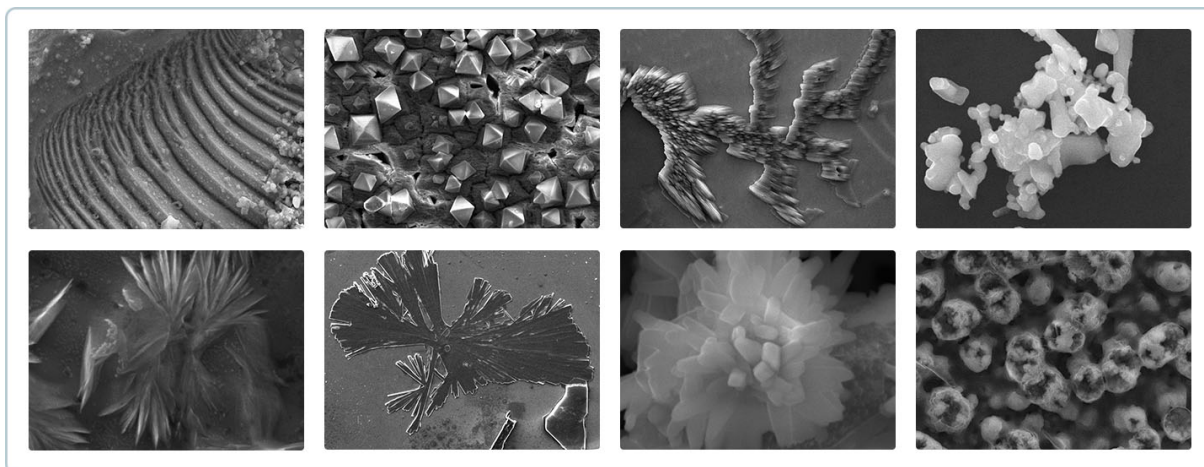


Figure 2. Examples of nanostructures formed on the surface of a semiconductor by methods of electrochemical processing.

is impossible to see such structures with the naked eye. To do this, special powerful microscopes are used, which allow obtaining images of the object with a maximum magnification of up to a million times. The critical element is the choice of the shooting area – the structure is often heterogeneous. Because of this, a careful analysis of the crystalline surface is needed.

Students were offered to explore nanostructures using a Scanning Electron Microscope (SEM). The principle of SEM is based on scanning the sample's surface with a concentrated beam of electrons. This creates a raster image (figure 3). Electrons interact with the atoms of the surface and create signals containing information about the morphology and chemical composition of the surface. Depending on the signal registration mechanism, several modes of operation of the scanning electron microscope are distinguished: reflected electron mode, secondary electron mode, cathodoluminescence mode, etc. The spatial resolution of microscopes depends on the characteristics of the electron-optical system that focuses the electron beam [20]. Some SEMs have a resolution of more than 1 nm.

It should be acknowledged that Scanning Electron Microscopes (SEM), as used in our study, are indeed sophisticated and costly equipment, which can be a barrier to their widespread implementation, particularly in high schools and smaller universities. The expense and technical expertise required to operate SEMs means that not all educational institutions have direct access to such technology.

To address this challenge and ensure broader access to the benefits of SEM technology, our project utilized Centers to collectively use the equipment. This approach allowed us to transfer samples of nanostructures created by students to a facility equipped with the necessary technology. Subsequently, students could engage in the research process remotely. Utilizing platforms like Zoom, the field of view from the SEM was displayed on screens, enabling interactive participation. Students could direct the microscope's focus in real time and select specific areas of the nanostructures for closer examination. This method overcame the logistical and financial constraints associated with direct SEM access. It introduced students to a collaborative, technologically facilitated mode of scientific inquiry, which is particularly valuable in broadening the educational reach of advanced scientific tools.

2.3. Ready to create Nanoart?

The photographs obtained using a microscope are black and white, but in the hands of an artist, they come to life and become true works of art. To colorize the images, we use graphic editors.

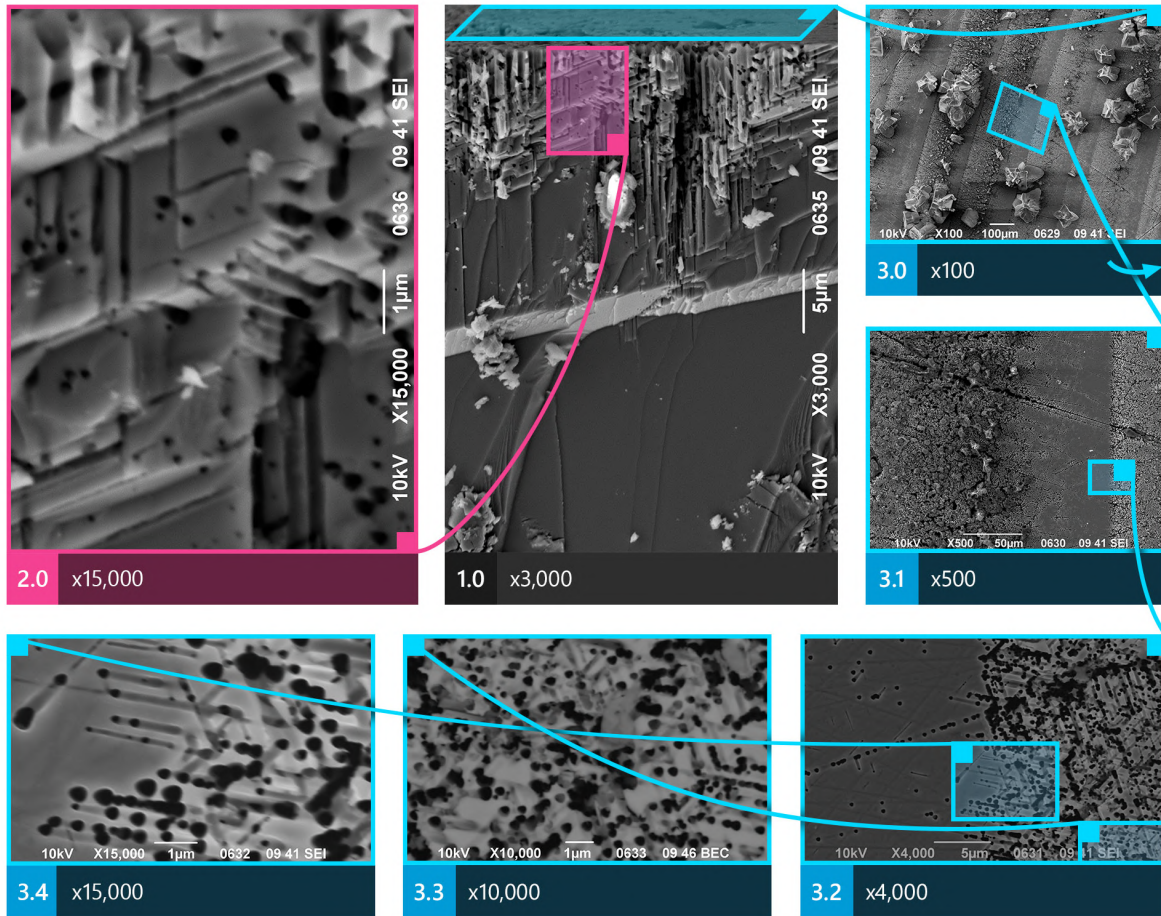


Figure 3. Collage of SEM-images of nanostructures demonstrating selection of photography area.

The process of creating nanoart can generally be conditionally divided into 5 stages (figure 4).

When discussing the process of creating Nanoart, we must understand that the most crucial stage is capturing the nanostructure on the microscope (figure 4a). This aspect distinguishes nanoart as a separate and independent direction in art.

The stage of distributing critical structures (figure 4b) is complex and has many approaches to achieving the necessary result. There are usually several main methods of division:

- Manually, using tools such as the Lasso Tool, Pen Tool, or Brush Tool;
- Division methods based on similar shades;
- Combined methods.

The main goal of this stage is to achieve a contrast between the fundamental structures and the background itself. The separated (delineated) layers with masks provide ease of managing the image coloring processes. It should be noted that this stage can be avoided, and coloring can be done by adding a filter, a gradient map, or other color overlays to the image, but in practice, these methods are only applicable in sporadic cases.

The image (figure 4c) is colored by mixing colors and overlay modes on individual layers. At this stage, achieving a result as close to the final one is essential without radical interventions in the original structure.

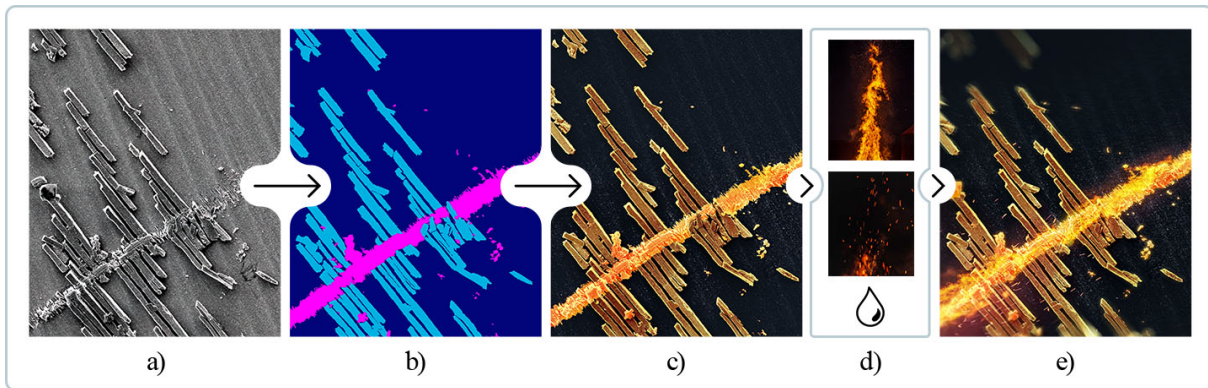


Figure 4. The process of creating nanoart is exemplified by the work “NanoArt”: a) Selecting the microscopic image; b) Delineating key structures in the image; c) Coloring the selected areas according to the initial scenario; d) Adding external textures and additional filters; e) Final graphic manipulations.

The coloring stage can be considered final, but since the finishing manipulations are delineated and have a precise action algorithm, it is logical to present them as separate sub-steps. For instance, we often notice a tendency to use additional textures or filters (figure 4d) to enhance the image’s focus and strengthen the final result’s effect. It should be noted that it is essential to maintain a limit; significant manipulations reduce the scientific value and quality of the work.

The final stage of the Nanoart creation process involves working with the graphic array obtained during the adjustments of shades and sharpness, adding mirror reflections, shading, reducing excessive noise, etc. This stage involves trying to achieve the best color spectrum and contrast to complete all details, set the necessary resolution, and finalize the framing of the image.

Adding an exciting color palette has aesthetic significance. Such images intrigue and attract with their uniqueness, geometric perfection, and aesthetic charm.

The color treatment aims to demonstrate the similarity between the macro and micro worlds. After such processing, one can see that the microscopic image closely resembles objects existing in the Universe (figure 5). Nature again demonstrates its laws, which are the same for both the macro and micro worlds.

It should be noted that the color processing of microphotographs has not only an aesthetic value. It also helps to reveal scientifically essential highlights in the image. In figure 6, you

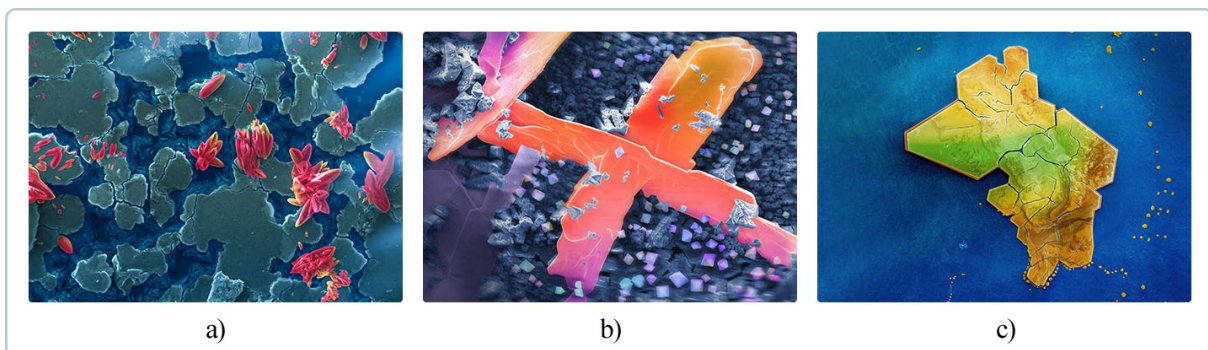


Figure 5. Examples of Nanoarts: a) “Lotus”; b) “Airplane”; c) “Africa”.



Figure 6. Nanoart “Nebula”.

can see our Nanoart “nebula”. The dark spots on the surface represent massive etching pits formed due to etching dislocations. The white spots indicate another phase. These are oxide inclusions that form on the surface during electrochemical etching due to chemical reactions at the electrolyte/semiconductor interface. The color variations of the nanostructure’s surface and mosaic shading indicate active surface processes during electrochemical processing. The shading can be considered as etching pits just beginning to appear.

2.4. Time to see the true beauty of science

Nanoart differs from all known art forms because its indispensable component is direct scientific experiment and experience. Visual art is an effective means of simplifying and understanding complex physical processes. In this context, nanomaterials’ SEM images can be considered harbingers of a new kind of art, namely the development of the Nanoart direction. New forms result from joint searches by artists (graphic designers) and scientists (nanotechnologists). The symbiosis of science and art generates interest in discovery and contributes to further understanding the worldview.

The barriers between science and art are erased in the objects of nanoart. We aim to show that science is aesthetics, inseparable from art. The interrelation of science and art is considered a factor contributing to the mutual enrichment of these spheres and social progress as a whole. Nanoart objects are an excellent way to engage young people and children in science, a way to understand the laws of nature, and an opportunity to get aesthetic pleasure from scientific research.

Nanoart is an art direction based on nanoengineering and graphic design symbiosis. From this position, a researcher-nanotechnologist should be perceived as a scientist and an artist capable of demonstrating the greatness of scientific thought through aesthetic visualization of the nanoworld.

In decorative and applied graphics, nanoart also has its adherents, as each painting in the nanoart style is lovely; it is a unique pattern that can decorate any material, product, advertising or multimedia product, etc. Nanoartworks are often used as interior design elements, book covers, etc. We are confident that this direction can influence other art forms; in particular, there is a perspective of using it as prints on fabrics and wallpapers, creating accurate 3-D

models and sculptures, and more.

3. Discussion

3.1. STEAM components

In the project that involves creating nanostructures through electrochemical etching, the integration of STEAM components – Science, Technology, Engineering, Art, and Mathematics – is fundamental and meticulously interwoven into every step of the process.

The journey begins with a deep dive into the scientific principles that form the project's foundation. Students immerse themselves in the realms of chemistry and physics, exploring the intricate details of electrochemical reactions and the properties of materials at the nanoscale. This exploration is not merely theoretical but an active engagement with the core scientific concepts that drive the nanostructure creation process.

Concurrently with this scientific exploration, there is an engagement with cutting-edge technology. The project requires sophisticated equipment, giving students practical experience in working with technology at the forefront of nanoscale research. This practical experience is invaluable, allowing students to translate theoretical knowledge into real-world applications.

Engineering also plays a pivotal role in this process. Students are tasked with designing the etching process, which involves meticulously considering various parameters such as voltage, current, and time. This phase is critically important as it requires a blend of theoretical understanding and practical application, compelling students to develop the process to achieve the specific nanostructure designs they envision.

Artistic expression is inherently tied to the project through the visualization of the nanostructures. The complex and often mesmerizing patterns that emerge from the etching process provide a unique canvas for artistic exploration. This phase transcends the traditional boundaries of science, allowing students to view their work through an artistic lens and explore the aesthetic dimensions of their scientific creations.

Mathematics is the thread that ties all these elements together. Precise calculations and measurements are essential for successfully executing the etching process. Mathematical skills are employed to fine-tune the parameters, ensuring the desired outcomes are achieved. This application of mathematics is practical and integral, highlighting its importance in scientific experimentation and problem-solving.

In this project, students are not passive learners; they are active participants who apply the multifaceted aspects of STEAM cohesively and pragmatically. This approach enhances their understanding of each discipline and illustrates the interconnectivity and relevance of these fields in real-world applications.

This seamless integration of science and art through an immersive educational approach enriches the student's academic experience and prepares them for a future where interdisciplinary and creative problem-solving skills are paramount. The project exemplifies a holistic educational model where students are deeply engaged, inspired, and empowered to explore and create at the intersection of diverse fields.

3.2. The educational role of Nanoart in STEAM education

The project uses a project-based learning (PBL) approach, a dynamic classroom methodology where students actively explore real-world problems and challenges. In this case, the task is to create nanostructures and their subsequent transformation into Nanoart. This method is particularly effective in STEAM education as it encourages students to apply interdisciplinary knowledge, think critically, and solve complex problems.

Incorporating student feedback into the evaluation of the Nanoart in STEAM education initiative provides valuable insights into the program's impact and effectiveness. Students who participated in the project reported a heightened interest and engagement with their

coursework's scientific and artistic components, reflecting a broad appreciation for the interdisciplinary approach. Many expressed that the visual and creative aspects of Nanoart made the abstract concepts of nanotechnology more tangible and understandable, enhancing their learning experience. One student remarked, "Seeing my scientific work turned into art made it feel more real and understandable".

Feedback highlighted the hands-on aspect of creating nanostructures as particularly impactful. Students appreciated the opportunity to apply theoretical knowledge in a practical setting, which solidified their understanding of scientific principles and fostered a sense of accomplishment and pride in their work. The artistic process of transforming these structures into Nanoart was seen as an innovative way to express their scientific findings, bridging the gap between empirical science and creative interpretation. "It's one thing to learn about nanotechnology in a textbook, but creating nanoart was inspiring", shared another student.

Moreover, students noted that the project encouraged deeper critical thinking and problem-solving skills. They valued the collaborative environment, where they could discuss and develop ideas with peers from diverse academic backgrounds. This collaboration often led to innovative solutions and ideas that might not have emerged in a more traditional educational setting. A student noted, "Working with classmates from different majors helped us see the connections between art and science in ways I hadn't considered before".

Overall, students perceived the integration of Nanoart within the STEAM framework as a refreshing and motivating approach to education. It demystified complex topics and highlighted the relevance and application of scientific knowledge in creative and practical contexts. "This project didn't just teach us about science; it showed us how to communicate science creatively", concluded a student. This feedback underscores the effectiveness of the project-based learning approach in engaging students, fostering interdisciplinary connections, and enhancing the educational experience across STEAM disciplines.

Nanoart is crucial in making nanoscience's abstract and intricate world accessible and understandable to students. By visualizing nanostructures through art, complex scientific concepts are translated into a format that is more manageable and easier to grasp. This approach demystifies aspects of nanotechnology, making them more approachable and exciting.

The integration of art into the scientific process encourages students to think creatively. This creative thinking is not limited to artistic expression but extends to problem-solving and conceptualization in scientific research. Students learn to approach scientific challenges with a more innovative and open mindset, an essential skill in contemporary scientific inquiry.

Nanoart embodies the essence of STEAM education by bridging the gap between science, technology, engineering, art, and mathematics. It provides students a platform to explore and appreciate the interconnectedness of these disciplines. This interdisciplinary approach is critical in preparing students for a world where the boundaries between disciplines are increasingly blurred.

Engagement with Nanoart equips students with unique skills and perspectives that are highly valuable in modern education and beyond. It prepares them to tackle future challenges with a holistic understanding and the ability to integrate diverse fields of knowledge.

3.3. STEAM and scientific art

Exploring the integration of Nanoart within STEAM education is crucially essential in positioning this initiative within the broader scope of scientific and practical efforts. Numerous projects worldwide encompass the interdisciplinary fusion of art and science, each uniquely contributing to our understanding of both fields [21, 22]. Projects like the "Art of Science" exhibitions at Princeton University demonstrate how artistic renditions of scientific phenomena can enlighten and inspire academic and public audiences [23]. Similarly, "BioArt" courses at various universities encourage students to explore biological concepts through artistic expression,

creating a rich dialogue between two seemingly disparate fields [24, 25].

Further exploration of similar experiments shows a growing trend in using nanostructures in educational settings. For example, the “Nanotechnology Summer School” at the University of Oxford integrates the creation of Nanoart as a method to engage students with nanoscience [26]. This approach makes abstract nanoscale phenomena tangible and stimulates students’ interest and understanding.

The inclusion of art in STEM education, transforming it into STEAM, has been driven by pedagogical recognition that interdisciplinary learning fosters more reliable educational outcomes [27]. Artistic engagement in science education encourages a constructivist approach, where students build new knowledge through hands-on activities and real-world problem-solving [28]. This methodology supports deeper cognitive connections and enhances students’ engagement, critical thinking, and creativity [29, 30].

The history of scientific art, from Leonardo da Vinci’s detailed anatomical sketches to contemporary digital micrography, demonstrates its longstanding role in enhancing the accessibility and understanding of scientific phenomena. Today, scientific art is not just a pedagogical tool but also a bridge to public engagement with science. By visualizing the nanoworld’s intricacies, Nanoart continues this tradition, providing both aesthetic pleasure and scientific insight.

Educational outcomes from STEAM approaches underscore significant benefits. Studies have shown that students engaged in STEAM activities demonstrate a more remarkable ability to apply knowledge across different disciplines, improve problem-solving skills, and increase creativity [31]. These results are particularly evident in projects like the one discussed, where the artistic visualization of scientific concepts—such as nanostructures—allows students to perceive and understand complex ideas more clearly.

Integrating STEAM by including art in the traditional STEM framework represents a transformative expansion that makes science more accessible, attractive, and comprehensible. Combining scientific inquiry with artistic expression, STEAM approaches enhance the educational landscape and appeal to a broader range of students, fostering a deeper connection to learning [32]. This interdisciplinary method enriches the understanding of scientific concepts, turning abstract theories into engaging, tangible experiences that resonate with diverse learners. Furthermore, STEAM education promotes creativity and critical thinking, essential skills in today’s dynamic world, making science more popular and more relevant. Ultimately, STEAM is a compelling educational model that prepares students to think holistically and innovate across boundaries, heralding a future where the synergy between science and art drives progress and inspires curiosity and exploration.

4. Conclusion

Integrating Nanoart in STEAM education represents a significant advancement in how interdisciplinary learning is approached. This study has demonstrated that students can comprehensively understand various STEAM components by creating nanostructures and transforming them into Nanoart. The project-based learning approach enriches students’ academic experience and prepares them for future challenges where interdisciplinary and creative problem-solving skills are essential. Nanoart, a bridge between science and art, is pivotal in making complex scientific concepts accessible and engaging. It encourages students to view scientific findings creatively, fostering innovation and a deeper appreciation for the interplay of different disciplines. This educational model is a testament to the potential of integrating artistic expression into scientific education, paving the way for a more holistic and engaging learning experience. Nanoart in STEAM education, therefore, stands as a powerful tool in cultivating the next generation of thinkers and creators equipped to navigate and contribute to a rapidly evolving world.

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Virtual laboratories for study technologies of environmental protection

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Abstract. This work is devoted to the use of virtual work for teaching bachelors in technologies of environmental protection. An analysis of publications in the field of using virtual laboratories in universities was carried out. The use of virtual laboratory work supports modern approaches to education, stimulates the learning process and creates conditions for more effective mastery of the material. The article describes an example of the development of laboratory work to determine the parameters of the dispersed composition of dust. Virtual laboratory work is developed as a web application, has a user-friendly interface, all data is saved into a database. Students can work at their own pace, repeat experiments, and adapt their approach to learning. The presented virtual laboratory is relevant to use in distance learning.

1. Introduction

A society that actively shares knowledge in the fields of science, technology, engineering and mathematics (STEM) has more effective means of solving modern problems in various fields of activity. Therefore, STEM education is a very important pedagogical direction [1, 2]. The core idea of STEM education is to integrate these fields and provide students with an integrated, problem-based approach to learning. Rather than studying these areas in isolation, students apply scientific and mathematical principles to solve practical problems and design technological solutions. It also stimulates students' interest in science and technology, developing technical skills and creativity [3, 4].

To effectively use STEM education, appropriate educational and methodological support and modern teaching aids are necessary [5]. One of the teaching tools for STEM education is virtual laboratory work [6, 7].

Virtual labs are a form of education in which students perform laboratory experiments using virtual environments and computer models instead of traditional equipment and real laboratories [8]. These virtual experiments can replicate real-life physical phenomena and processes, providing students with the opportunity to gain hands-on experience, analyze data, and explore scientific concepts. Such laboratories are often available online and can be used in both distance learning and traditional learning. Virtual labs provide a safe and flexible alternative to traditional laboratory classes, especially in the context of science, technology, engineering, and mathematics education.

The development of information technologies, hardware and software, especially modern virtualization tools has contributed to creating realistic virtual laboratory environments. Due to



the availability and popularity of smartphones, tablets and other computing devices the use of virtual laboratories has become much easier and more accessible. This has become especially important in the conditions global pandemic, and for Ukraine under martial law. Because virtual labs are ideal for distance learning. In this case, students can complete virtual laboratory work at any time convenient for them, which provides flexibility in learning and allows each student to choose the pace and order of assignments. Virtual labs allow students to repeat experiments over and over again, adjust parameters, and see instant results. This promotes a deep understanding of the material.

Most importantly, virtual labs can easily integrate with other technologies, such as computer modeling, simulation, and data analytics, to promote a deeper understanding of physics concepts. The level of modern information technology makes it possible to develop virtual laboratory work for various branches of science.

2. Literature review

Researching science teachers' opinions, this study shows that using virtual labs positively affects how engaged, motivated, and successful students are in learning [9].

The study [10] establishes that the use of virtual labs significantly improves students' problem-solving skills in comprehending the electricity concept, particularly evident in their superior planning and implementation abilities compared to traditional instructional method. Positive experience in developing virtual laboratory work also in the distance learning system "Kherson Virtual University" for the study of physics [11]. The research [12] demonstrates that implementing cooperative learning with virtual media significantly enhances students' creativity. Creative abilities have become a vital component in the global competitive environment of the 21st century, emphasizing the importance of innovations in education to foster students' creativity.

The article [13] discusses an experimental first-year seminar employing game-based learning, revealing positive enhancements in students' confidence regarding creative problem-solving abilities, despite a slight decline in their beliefs related to personal creative identity.

Gunawan et al. [14] demonstrates that the developed virtual lab model effectively enhances the problem-solving skills and creativity of future physics educators, as evidenced by the increased performance in both aspects, particularly in the experimental group compared to the control group. Students are very excited about incorporating virtual tools into the learning process.

During 2.5 years, The University of Sydney's virtual lab [15] had 4833 students visit 7952 times, with 71.5% of surveyed students reporting better learning outcomes. These results highlight the lab's effectiveness and affordability as an educational tool.

The review by Kiv et al. emphasizes the need for rigorous evaluation measures in understanding the true potential of immersive virtual reality, particularly in the context of its application as virtual laboratories, urging comprehensive assessments to comprehend their effectiveness in modern education [16]. However, a portion of students expressed a preference for a combination of online and face-to-face laboratory sessions [17].

A comprehensive study by Reeves and Crippen of the impact of virtual resources on student learning over the past decade underscores the importance of personal interaction between teachers and students, warranting further research [18]. Recent research shows that today there is already a large number of publications on the use of virtual work. But despite this, the interest and need for them are very relevant [19].

Therefore, the authors also devoted their work to developing virtual labs for students at their university. This article describes the results of this work using the example of laboratory work for specialty 183 "Technologies of environmental protection".

3. The methodology of the laboratory work

Laboratory work is an effective form of educational organization that allows students to independently delve into the educational material. It is carried out both when studying new topics and to repeat learned material. This hands-on approach requires specialized equipment and different implementation methods. The importance of laboratory work is especially evident in the study of ecology, since experimental work is necessary for a complete understanding of natural processes. Through this work, students develop both intellectual and practical skills that are critical to their learning and development.

In connection with the transition to online learning due to military operations in Ukraine, there was an urgent need to create a virtual laboratory for effective student training. This is due not only to maintaining the quality of education, but also to financial restrictions caused by the situation in the country.

Virtual laboratories can save significant resources compared to traditional physical laboratories. They can reduce costs for equipment, supplies and maintenance. Also, the use of virtual laboratories ensures safety because they eliminate the risk for students associated with working with hazardous substances or complex equipment. But the main important advantage is the ability to expand research parameters in virtual laboratory work. Because in real conditions a larger number of components of the natural process is needed. And when simulating this process in virtual conditions, it is possible to organize a variety of materials and their parameters.

This article is devoted to the development of virtual laboratory work on the topic “Study of the parameters of the dispersed composition of dust”. The purpose of the laboratory work is to familiarize students with methods for determining the main parameters of the dispersed composition of industrial dust, to acquire practical skills for students in constructing histograms, differential and integral particle size distribution curves, and finding the average size and standard deviation of particle sizes. This work is intended for bachelors who study environmental protection technologies.

The dispersion of particles of industrial aerosols, or dust, is characterized by the totality of the sizes of all constituent particles.

As a rule, the composition of dust is polydisperse, i.e. contains particles of various sizes. Monodimer dusts, i.e. those that contain particles of the same size (or a narrow range of sizes) of particles are practically not found. Thus, for polydisperse aerosols it is necessary to have information on the distribution of mass or total number of particles by their sizes, the proportion of particles of individual sizes, the average particle size, etc.

The dispersion of dust is determined by a number of fractions (or so-called fractional composition), i.e. shares of the total aerosol mass, the particle sizes of which are in a certain range of values accepted as the upper and lower limits.

In general, the particle sizes of industrial aerosols (dust) are formed under the influence of many factors, the influence of each of which cannot be accurately taken into account. In such cases, the laws of probability theory and mathematical statistics come into play, namely: the particle size (its equivalent d_e or sedimentation d_c diameters) is considered as a random variable. Then it is convenient to describe the dispersion properties of dust by the probability distribution function $m(d_e)$ of the mass of aerosol particles over its size d_e .

The function $m(d_e)$ is equal to the percentage ratio of the mass of particles whose size is less than or equal to a certain size d_i to their total mass ((e.g., (1)).

$$m(d) = \frac{\sum_1^i F_i(d \leq d_i)}{\sum_1^n F_i}, \quad (1)$$

where $F(i)$ -distribution of the total mass of dust particles by fractions.

It has been established that for aerosol particles of industrial dust and powdery materials the

law of lognormal distribution is most characteristic, which can be mathematically expressed as:

$$m(d) = \frac{100}{lg(\sigma) \cdot \sqrt{2\pi}} \int_{-\infty}^{lg(d)} \exp\left(-\frac{(\lg(d) - \lg(d_{50}))^2}{2 \cdot \lg(\sigma)^2}\right) d(\lg(d)), \quad (2)$$

In formula (2) are indicated: d_{50} – so-called median particle diameter (median) of dust, for which 50% of the total mass of dust lies before this value, and 50% of the mass after this value; $lg(\sigma)$ – standard (mean square) deviation of the logarithms of the current particle diameters d from their average value.

After a series of mathematical transformations, the standard deviation can be determined using (e.g., (3), (4)).

$$\sigma' = \frac{d_{50}}{d_{15.9}} \quad (3)$$

$$\sigma'' = \frac{d_{84.1}}{d_{50}} \quad (4)$$

The calculation of these indicators in normal laboratory work is performed as follows:

- construct a graph of the distribution of the total mass of dust particles among fractions $m(d_i)$ and the mass fraction of dust particles for fractions of less than a given size $m(d)$ – according to the so-called “full passages”.
- draw through the middle of the ranges the integral curve of the distribution of the mass fraction of dust particles by fraction.
- select points on the ordinate axis that correspond to the dust mass fraction of 15.9%, 50% and 84.1%.
- find for these points, using the integral distribution curve, the corresponding values for the diameters of dust particles $d_{15.9}$, d_{50} and $d_{84.1}$.
- calculate the standard deviation of particle diameters (e.g., (3), (4)).
- theoretically, the values σ' and σ'' must be $\sigma' \approx \sigma''$. However, in practice, as a rule, these values differ, so the standard deviation of particle diameters is calculated as their arithmetic mean

As a result, the required values of d_{50} and, characterizing the fractional (dispersed) composition of dust. Next, based on these parameters, one of five dust classification groups is established:

- very coarse dust (coal);
- coarse dust;
- medium-fine dust (for example, cement)
- fine dust (for example, suspended atmospheric dust);
- very fine dust.

For this process, a virtual laboratory was developed as a web-based application. The main purpose of the software is primarily to help visualize the necessary information. At the same time, the work should not be transferred entirely to the program, without the participation of the student. And in the program it is necessary to develop tools with which the student can do the work.

In general, the following requirements were put forward for virtual laboratory work:

- interaction is via a browser, so the interface is web-based;

- storing all parameters of laboratory work and the results of its implementation in a database;
- ability to select parameters for different types of dust;
- presentation of experimental results in the form of a graph;
- functionality for creating a chart yourself using visual tools;
- possibility to change process parameters.

To successfully implement a virtual laboratory to determine the parameters of the dispersed composition of dust, modern development tools and technologies were used to ensure the efficiency, reliability and interactivity of the project:

- HTML, CSS and JavaScript are basic languages for creating a web application interface. HTML is used for page structure, CSS for styling and appearance, JavaScript for implementing dynamic elements and user interaction.
- Python and Flask: Flask is a microframework for server-side development. Python is used to process queries, interact with the database and provide the required functionality.
- SQLite: A lightweight and compact relational database used to store information about dust types, their properties, and experimental results.

Technologies were also used to work with data: RESTful API for data exchange between client and server about types of dust, their properties and research results; AJAX (Asynchronous JavaScript and XML) is a technology that allows you to interact with the server asynchronously without reloading the page, and is used to dynamically update client-side data.

The Matplotlib library was used to visualize the experimental results. Graphs and diagrams provided users with the ability to quickly and clearly analyze the data obtained, make changes and observe the impact on the dispersion parameters.

4. Results

As a result, a functional and convenient tool for studying the parameters of the dispersed composition of dust has been created. To begin with, the student should go through the first stage, in which it is necessary to select the type of dust to consider and obtain the fractional composition. The results of these processes are shown in figure 1. Shows the screen for this step.

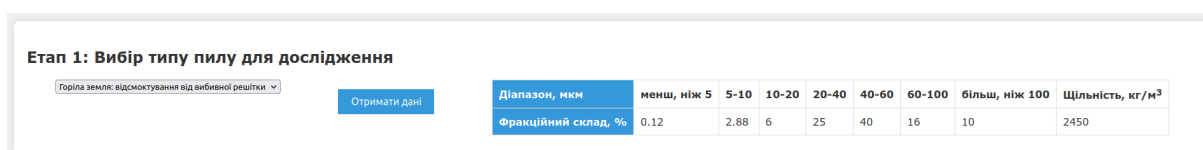


Figure 1. First stage of work.

Next, in the virtual laboratory work, a distribution graph of the total mass of dust particles by fractions. The student must complete further actions independently. To draw an integral distribution curve of the mass fraction of dust particles by fraction, you can select a color and draw a line on an existing graph. Using other marker colors, you need to mark the points corresponding to the dust mass fraction of 15.9%, 50% and 84.1%. For these points, using the integral distribution curve, it is necessary to find the corresponding values of the diameters of dust particles $d_{15.9}$, d_{50} and $d_{84.1}$. The student must also do the calculations independently and fill in the required fields with the results in the virtual laboratory work window. The results of these processes are shown in figure 2.

This window also provides an opportunity to answer security questions. All laboratory results are saved in a database. Thanks to this, the teacher can check the results of the work at any time. The student may redo the lab with different data.

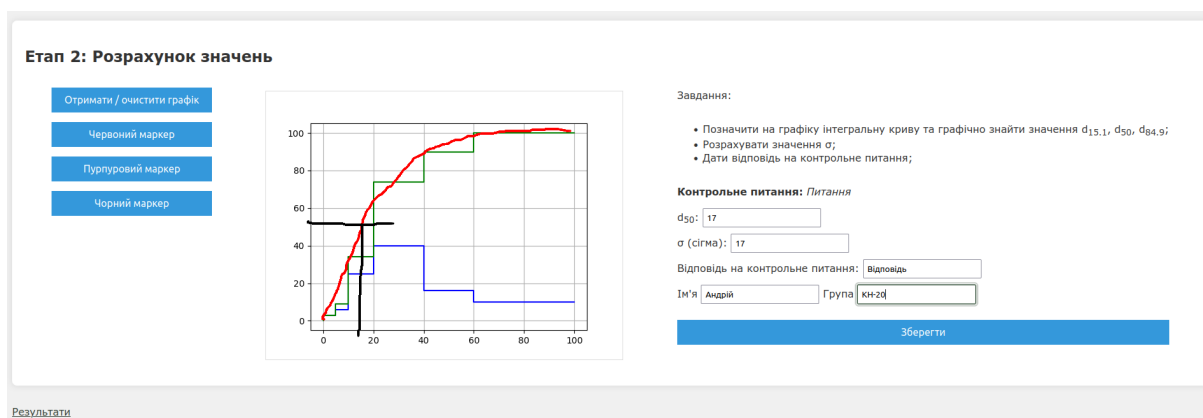


Figure 2. The main window of the program for determining the dispersed composition of dust.

5. Conclusions

Thus, a virtual laboratory work has been developed to determine the parameters of the dispersed composition of dust. This work is an example of training for bachelors of a specialty “Technologies of environmental protection”. Also, this laboratory work can be used in studying the discipline “Ecology” of other technical specialties.

So, virtual laboratory work combines the use of different areas: laws of nature and the environment, information technology and software, mathematical methods.

Also virtual labs provide flexibility in learning. Because students can perform experiments at any time, from anywhere, which is especially important during distance learning or in conditions where access to laboratory space is limited.

Students can also repeat virtual experiments an unlimited number of times, allowing them to improve their skills and understanding of the material. In addition, virtual laboratories often provide the ability to customize experimental parameters, which allows for adaptability and variety in learning. Virtual labs are easily scalable to serve large numbers of students, making them attractive to universities with large student populations. These factors have made virtual labs an attractive option for universities looking to improve the educational experience, save resources, and provide students with state-of-the-art learning tools.

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Application of chatbots for enhancing communication skills of IT specialists

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Abstract. The paper deals with the urgent issue of application of chatbots in training IT specialists for enhancing their communication skills. The background of application of chatbots in learning from using ordinary chatbots which converse in the language studied to development and implementation of special chatbots created for studying has been described. Main features, advantages and disadvantages of certain chatbots have been analysed. Taking into account the results of the analysis the teaching-oriented chatbot BEbot for developing communication skills of IT specialists has been introduced, some specifics and challenges of its creation, its peculiarities and contents have been presented. It is emphasized that along with developing business-like communication skills, language-in-use skills, cultural distinction knowledge, command of business writing style and delivering presentations in a businesslike manner have been enhanced through communication with BEbot. The results of the surveys of students on their experience in the chatbot use and their particular experience with BEbot have been highlighted.

1. Introduction

In recent years with the development of information and communication technologies chatbots have become omnipresent in numerous spheres of people's lives as service providers, online consultants, troubleshooting service providers, digital reference books, virtual teachers etc. and their number is constantly increasing.



In scientific sources, there are numerous terms for chatbots (chatbot-like systems): chatbot, conversational agent, conversational tutor, human-computer dialogue system, machine conversation system, conversational dialogue system, virtual agent, intelligent agent, dialogue system, chatterbot etc. The definitions for such kinds of systems are also different, becoming more complex and sophisticated with the development of information and communication technologies. Brennan considers a chatbot as “an artificial construct that is designed to converse with human beings using natural language as input and output” [1]. Jia et al. give a very simple definition of the term: it is “a program that can pretend to ‘chat’ with a human user in a certain natural language” [2]. Pérez et al. define a chatbot as “a tool that combines artificial intelligence and natural language processing or other technology, which enables it to interact to a certain level of conversation with a human interlocutor through text or voice” [3].

Chatbots have already been widely applied for education purposes as they have certain advantages. They can serve as educational agents decreasing the workload of human teachers or supporting the main education process [3].

Pérez et al. in their systematic review of the literature on chatbots in education classified chatbots into two categories: service-oriented chatbots and teaching-oriented chatbots. Service-oriented chatbots may include different services both for students and for university departments: student queries, procedures for admission and registration processes, administrative tasks, answering FAQs about universities, their curricula, student’s life and others. Teaching-oriented chatbots as their name says are intended to “generate knowledge for specific students, usually on a specific topic”. These chatbots as researchers state can encourage learning, promote studying, improve their skills etc. Teaching-oriented chatbots are subdivided into formal and nonformal ones according to their application in education [3].

2. Application of chatbots for development of communication skills

Application of chatbots for development of communication skills has had a rich background: from usage of ordinary chatbots which converse in the language studied to development and implementation of special chatbots created for studying languages. Undoubtedly, as the main purpose of studying a language is communication, chatbots can be efficient tools for practicing dialogues and some kind of immersion into the language environment.

According to the purpose of learning, language learning chatbots differ in some way from ordinary chatbots “in their goals, their approach, and their users’ characteristics, thereby effectively creating a new interaction paradigm” as Divekar et al. suggest. The researchers state that language bots have to be intended for users who do not know “the language of interaction, and the purpose of the conversation is language education through task completion rather than task completion itself” [4]. Huang et al. present main common features of language learning chatbots: their availability for users 24/7; provision of extra information such as expressions, questions and vocabulary; assistance in repetitive activities continuously [5].

Huang et al. identify five ways to use chatbots for language learning: as interlocutors (language learning practice, learning skills activity, group discussion coordination), as simulations (role-playing, learning scenario representations), as helplines (responding to requests for assistance), for transmission (delivering well-targeted interventions) and for recommendation (providing level-appropriate contents) [5].

The ideas of possible application of chatbots for language learning become to appear in the early 2000s. In 2006 Fryer et al. suggested that chatbots could be used to practise a foreign language, as they had certain benefits such as their price and convenience of their usage. They tried to implement ALICE and Jabberwacky bots which were not initially intended for foreign language learning into the educational process. They asked their students to use these bots and according to the answers presented the following advantages of chatbots: most students felt more relaxed while talking to a bot; bots could repeat the information continuously; students could

practise in reading and listening; bots were interesting for students because of their novelty, students were able use numerous language structures and vocabulary they could not use in the classroom (slang and taboo words); chatbots could “provide quick and effective feedback for students’ spelling and grammar” [6].

Similar attempts to use ordinary chatbots for language learning were made by Shawar et al. [7] who developed algorithms for adapting or retraining a chatbot to meet student needs. They created one ALICE version for learning spoken Afrikaans and a bilingual version as an Afrikaans/English chatbot. The researchers concluded that “adaptive chatbots can foster language learner autonomy, giving students the opportunity for independent active learning of conversation skills”.

Seneff et al. presented the results of implementation of multilingual dialogue systems developed for learning the Chinese Mandarin language as the foreign language for native English and Spanish teachers [8, 9]. Students could communicate with the system by having a goal-directed dialogue in writing or using a microphone on topics within a travel domain.

In 2009 the group of researchers and practitioners developed CSIEC (Computer Simulation in Educational Communication), a human-computer dialogue system for English learning. The most specific features of the system were a multimodal user interface and selectable chatting patterns. It meant users could chat with the chatbot opting for the text mode or talking into a microphone. The robot that had an avatar provided written messages or spoke with users with a synthesised voice. The robot had a built-in function of checking grammar and spelling upon request. The chat topics for conversation could be either free (unlimited) for intermediate to advanced users or prescribed (limited) for elementary level students. The most progressive features of the system were: options to choose the interlocutor, depending on the preferable mode of communication, the possibility to have a dialogue on any topic depending on the information about the user, guided chatting in a given scenario for drill or examination, the function of presenting two robots chatting on a given topic [2].

Recently, numerous studies of the application of chatbots for foreign language learning have been carried out. The main aspects of contemporary research on chatbots in foreign language teaching are technological and pedagogical ones. The researchers study existing chatbots to examine their application in language learning and suggest prospects for further development or develop their own chatbots to complement foreign language courses at the universities or as additional conversational agents.

Pham et al. [10] have developed the English Practice chatbot for mobile devices for learning vocabulary and new lessons. The English lessons have multiple choice questions for checking comprehension. Na-young et al. [11] have studied several chatbots for foreign language learning and concluded that they have positive influence on student communication skills as they can increase the quantity of student-chatbot interactions, foster their motivation, and raise their interest in learning. Ruan et al. [12] have developed BookBuddy, “a scalable virtual reading companion that can turn any reading material into an interactive conversation-based English lesson”. The chatbot supports two modes of conversation: general conversation (popular English expressions) and book-related conversation (questions and answers related to the book).

Haristiani [13] has carried out the research on available chatbots for foreign language learning, made their categorization (flow, artificial intelligence and hybrid chatbots), studied their advantages and disadvantages. The researcher has developed Gengobot which is intended to provide a Japanese grammar learning medium for beginner level of Japanese language learners. The chatbot also has grammar contents in English and Indonesian, and is integrated with LINE, the most popular social media application in Asia. The developed chatbot is a flow chatbot, which presents Japanese grammar and provides exercises for practicing and tests. As the author states, the chatbot functionality is limited and is to be extended in the future.

Petrović et al. [14] have studied four popular chatbots for foreign language learning regarding

two aspects: the speaker aspects (the skill level, language diversity, domain, and interaction modality) and technology aspects (the dimensions include dialog type, knowledge base, and availability). The authors state that in December 2020 there were only four chatbots “that support real-time dialogue with users, i.e. provide immediate answers to prompts, and ask relevant follow-up questions, very much like in any natural and spontaneous conversation with a real person”. On the basis of the research results the authors offer prospective direction for the chatbot technology development in the context of education and research: a new methodology for technology-supported language learning, a technology for personalized language learning and a novel, online conversational service for learning languages at scale.

Fryer et al. [15] have examined two chatbots for foreign language learning (Cleverbot and Mondly) and suggested some ideas on how to structure chatbots to make them more useful for foreign language learners. The researches have discussed the necessity of supporting generative e-learning, the urgency of development of multiple chatbots which provide different answers and ask different questions; the need of creating chatbots for specific audiences; the necessity of providing immersive experience for learners.

Kim et al. [16] have presented the design principles and architecture of a second language learning voice chatbot. The South Korean researchers have developed a chatbot Ellie with three chat modes: 1) General Chat which is aimed at human-chatbot conversation about personal information, interests and thoughts; 2) Task Chat which is intended to problem-solving activities using a foreign language; 3) Skills mode which allows users to “practice their pronunciation and vocabulary or play game-like language activities for speech enhancement”. The developers state that the chatbot requires some improvements, but can “serve as a useful reference for future foreign language chatbot projects”.

3. Analysis of chatbots for language learning

In order to determine the user-friendliness and efficient technical abilities necessary for learners before designing our own chatbot, we have studied several online chatbot builders and the provided chatbots. The profound chatbots introduced by authoritative linguist and educator teams in their language learning applications have been also used in order to specify the communication manner, attractiveness and prepossessing for young adults. Thus, the chatbot features which have been analysed are also advantageous for prospective Business English learners. These beneficial parameters are the abundant content (vocabulary, grammar, culture sections), the diversity of the content formats (texts, visuals, speech patterns, audio, web links for outsource additional information), communication manner (the high level of the AI integration for adequate mock chat provision), user-friendliness (usage simplicity, appropriate interface, reminder system, request for user feedback), consolidation section (review tasks, tests, quizzes). The mentioned above features are not necessarily present in every application to the full extent, but their presence is an additional constituent for the application attractiveness for English learners.

The comparative analysis of several smartphone applications has been very helpful for selection of both the linguistic aspects and forming their coherence and for making the chatbot-to-be character outline. The following English learning applications have been chosen for the analysis (table 1): Duolingo, Mondly, Virtual English tutor, Memrise, EnglishCareerBot.

Duolingo is one of the most famous language learning applications. More than 150 mln people have chosen the application whose slogan is “The free, fun, and effective way to learn a language” [17]. The smartphone learning application is really attractive for teenagers because the gamification principle is the basis of all the activities. In 2006, Duolingo launched a chatbot feature mimicking texting with a real person in French, Spanish and German. In the course of time, three characters were developed to diversify the communication – Chef Robert, Renee the Driver and Officer Ada who gave dissimilar responses in order to give the learners the choice

Table 1. Chatbot applications for learning English.

Application	Duolingo	Mondly	Virtual English tutor	Memrise	English Career Bot
Aspect	General English	General English	General English	General English	Business English
Application version	mobile	web and mobile	mobile	web and mobile	mobile
Voice-enabled chatbot	+	+	+	+	-
Manifold set of speech patterns	+	+	-	+	-

of the communication partner or partners. The texting scaffolding were the hover hints for separate words and the ‘help my reply’ button, demonstrating several suggested answers for real-life conversations to the learners. The chatbot feature was accessible only in the Duolingo Iphone app for learners who have accomplished a specified number of lessons. After a couple of years the chatbot option was pulled from the app and unfortunately it is no longer available. However, Duolingo alternative is the Stories lab. The stories are mini-conversations between two of ten Duolingo characters and the learner should follow along their dialogue and answer questions or choose the most suitable option in accordance with the conversation logic.

Mondly by Pearson [18] counts more than 100 million people learning English. This application invites to learn 41 languages among which there are rare or so-called bespoke languages as well as the set of varieties of a language (like British or American English). There are four Mondly apps – Mondly, Mondly Kids, Mondly AR (AR stands for augmented reality) and Mondly VR (VR stands for virtual reality). In our previous research we studied the Mondly VR mobile application in the English course for the undergraduates majoring in Computer Science [19, 20]. Both the lecturers and the undergraduates have considered it to be the most efficient compared to five other VR applications, some of which offer chatbot experience, too. The Mondly apps suggest short lessons, medium gamification level and unobtrusive encouraging technique and set of reminders to keep a learner progress and advance with the lessons. The chatbots maintain speaking activities and improve pronunciation though they differ in each Mondly application. In Mondly, the chatbot tool is aimed at simulation of an audio based real conversation with a native speaker. The learner listens to a native speaker, records their own voice in response. The advantage over Mondly rivals is that learners can replay the recording and compare it to the native speaker pronunciation and understand what needs to be practiced and improved. In Mondly AR and Mondly VR, the voice-enabled chatbots are aimed at immersion into the learning environment. For using Mondly AR, a learner uses an AR application to scan their own room or office and augmented reality technology generates a CGI (computer-generated imagery) teacher and animations. For using Mondly VR users need an Oculus headset through which the application immerses them into simulated virtual environments (like a shop or a train) in a variety of situations which require them to speak to virtual locals (shop assistants, waiters, fellow travellers). Interacting with animations complements the standard lessons from Mondly applications with all its useful functions (like hover or hint translations, sets of synonymous phrases for a response, repeated listening to chatbot phrases and own recorded submitted responses). All the chatbots speak in a clear human voice and the multiple dialogue versions are elaborate and effective.

The application from Paphus Solutions Inc. called Virtual English Tutor was released in May 2022 and features a Bot Libre chatbot. The Bot Libre Platform is a free open source platform for creating chatbots and using artificial intelligence for the web, mobile, social media, gaming, and the Metaverse [21] – it is currently integrated with 12 social and chat platforms. The Bot Libre community is growing which results in more than 100,000 bots created by 500,000 registered users for customer service, sales, advertising, technical support, or just for fun. Virtual English Tutor for Android is so far not very demanded, it has more than 1,000 downloads from Google Play. The language learning application is aimed at practicing conversational English. The lessons are divided into three categories (greetings, job interviews, dating) [22]. Within each lesson, the learner communicates with a chatbot and can choose between speaking and typing. The advantages of the application are very simple navigation and quick response from the chatbot. Nevertheless, the range of response phrases is quite limited, the repetitiveness of the questions and duplication of phrases to enhance the dialogue can be quite annoying. Each lesson includes practicing only five to seven phrases, the chatbot insists on communicating in complete phrases, not in curt replies. The speech recognition option functions only when the demanded word or phrase is pronounced slowly, loudly and with clear pauses between words, so mimicking native-speaker pronunciation and intonation does not result so far. The company is going to create more lessons with the active engagement of English teachers so the app could facilitate curriculum-based content.

A Ukrainian language learning chatbot has also been tested. The English Career Bot designed by the IT-course platform GoIt [23] provides learners with strategies and materials for preparation for a job interview in the IT sphere. A free of charge “7-day marathon” is introduced in a Telegram channel. A subscriber is encouraged to study text and audio materials to accomplish seven successive units within seven days. There is a true-false test and a speaking task. The learner has to record and upload their detailed answer for a typical interview question. As appropriate, the learner can adapt the introduced text (and its audio version), change their major, desired position, the company name etc. and after practicing performing the response, record a message (ten seconds or longer). The advantage of English Career Bot is its focus on one purpose and its thought-out example-like resources. The identical structure for all seven units can be perceived positively but in the chatbot extended version (twenty units) it can seem tedious. Beneficial is a reminder system for learners who are likely to miss the every-day deadline or not to accomplish the test within a specified time interval. It is important, because there is no prior notification about expelling the learners who have failed to meet the deadlines. The disadvantage is the excessive amount of the Ukrainian language in the chatbot communication. Nevertheless, English Career Bot is an effective learning tool for IT undergraduates, graduates and job seekers who look for employment with reputed international companies.

Memrise is a language learning application in two versions (a web and a mobile application). The Memrise creators oppose learning experience with Memrise to convenient learning from textbooks. They state that using Memrise is an enjoyable and effective way to memorize characters, vocabulary, and phrases. The basis of such confidence is the course diversity. There are 13 languages to choose from subscribers. The learners may freely navigate between courses and levels, moreover, alongside official Memrise courses there are hundreds of user-created courses. The official courses outmatch the outsource courses because they have assurance of their quality and accuracy, elaborate content, high quality audio and video. They also have an AI chatbot, MemBot [24], whose ultimate goal is to make learners feel confident when communicating in another language with others in the real world. Membot is powered by artificial intelligence and produces human-like text. Chatting to MemBot is really absorbing. The chatbot is asking a first question, the next question bases on the previous learner’s response and encourages the learner to share additional information and details. The experience is welcoming, because the follow-up phrases demonstrate MemBot’s full attention and friendly

support. The dialogue on a specific theme can include 5 to 10 lines from each counterpart. Then the learner can start a new conversation within the same theme but with different phrases because Membot's vocabulary is quite sophisticated and elaborate. The creators disclaim any bias and discrimination in MemBot communication and promise to remove any phrases claimed as inappropriate by the chatbot users. The Memrise team emphasize that the chatbot is being improved as the technology is pretty new. Actually, Memrise has had chatbots and grammar bots previously, but they were removed in 2020 both from the application and on the Memrise website. The chatbot features have not proven to be useful to most Memrise learners and have taken up resources for the creators to keep supporting them properly. Instead, after two years of designing, Memrise introduces its rewarding on-demand AI language language partner, with a lifelike language.

4. Development of the chatbot for development of communication skills

The teachers of the department of foreign languages have developed a Business English course for IT specialists which provides communication of undergraduates and graduates with a chatbot. The chatbot named BEbot (Business English bot) enhances both business communication skills and command of English. The learners can only type to provide answers and dialogue lines because there is no speech recognition function. The developed chatbot is of a hybrid type, as it can understand and communicate with users, but follows the pattern determined by the developer.

While designing, building and introducing BEbot, the teachers had the following challenges:

- 1) to design a learning means which assists the Business English textbook but does not copy it. In order to extend learning material a supplementary exercises coursebook has been developed in accordance with the planned chatbot content.
- 2) to find the balance between the instructional and entertaining material and to keep learners' focus in the first category. The share of the English entertaining material with lower educational value for the Business English course does not exceed 15 percent and includes mostly videos and real life content like funny facts or visuals.
- 3) to choose various additional multimedia online resources with free access in order to enhance reading and listening skills. Therefore, links for free online audio and video resources from prominent publishers (Pearson, Express publishing, Longman) have been retrieved in order to enhance students' listening skills.
- 4) to build a chatbot with a very manifold structure and to make it look comprehensible for learners. The content has been carefully analysed and organized in 12 themes with 3 aspects each.
- 5) to choose an appropriate testing means for different language skills. As reading, writing, and listening can be assessed through different chatbot technical abilities, different types of tests (matching, gap filling, and extended answers) have been developed.
- 6) to create an impressive character, intriguing and unobtrusive at the same time. BEbot has been developed taking into consideration character traits of online influencers and popular fictional characters presented by the film industry within the last 2 years.
- 7) to automate communication processes according to predetermined learning scenarios. In order to make BEbot a more attractive communication counterpart for young adults, a nontrivial and extensive set of phrases which includes youth slang and informal communication patterns has been provided.
- 8) to let students unbiasedly understand the purpose of the chatbot. BEbot was introduced to students in the first week of the term. After one week of using it in combination with the Business English coursebook, students had to make the decision on their own, if they are going to use BEbot and for what purpose.

- 9) to incite student's regular turn to BEbot. Since the group decided to use BEbot, the supplementary exercises and additional learning resources represented in the chatbot became relevant for the learners.
- 10) to encourage students to prolong active communication with BEbot after the Business English course is over. BEbot has been promoted not just as a communication partner for Business English learners, it has been specifically highlighted and confirmed within the course that BEbot provides lots of links for efficient and sought-after resources.

The Business English course includes several topics aimed at forming skills in applying for a job, having a job interview, establishing business relations and maintaining contact with employers, colleagues, partners and clients, writing and responding to business letters, communicating face-to-face, via telephone and online (figure 1). The course aspects include also forming students' awareness of equality, diversity and inclusion policy and enhancing intercultural communication. Each section mentioned above has focus on a coherent English language aspect (vocabulary and grammar). Several themes of the Business English course are presented in table 2.

For instance, the "Job interview" section has a vocabulary/glossary subsection, grammar subsection (a verb+preposition structure, double object verb formations). The vocabulary category in the chat menu links this subsection to the glossary where distinct words are explained and used in a sample sentence. There are also collocations and phrases important for conducting and having a job interview. Some speech patterns are combined in short dialogues. The grammar category suggests learners to refresh their skills in choosing between Past Simple tense and Present Perfect, as well as between Present Perfect and Present Perfect Continuous tense for representing the past events and current activities and achievements in their life and work. The usage rules of type I conditionals are supposed to be revised in order to equip learners with speech means for talking about possibilities and future results of real actions. For discussing career prospects the importance of grammar points like Future Simple and the going to + Infinitive construction should be focused on. The verb plus preposition and double object verb formations should also be reviewed as their usage is a challenging grammar theme and voluminous linguistic material for memorizing.

Another important subsection helps students refresh their knowledge and acquire new information on behaviour patterns leading to success in the interview, recommendations on appearance and dress code, and intercultural aspects of applying for a job in foreign companies (like Japanese, American, German, French).

The "Job interview" section is the fourth one in a sequence of themes in the Business English syllabus. By the time, when users enter communication with BEbot within the job interview discussion they have familiarized with the techniques of chatting with this character. Within the first theme "Acquaintance" BEbot asks standardized questions about name, affiliation, study, hobbies, and gives bland short answers like "Well done!", "Good for you!", "Please, tell me more". Gradually, BEbot becomes more strict and ironical, the chatbot extended answers are supposed to puzzle and to intrigue the communication counterparts. The phrase samples for some chatbot reactions are presented in table 3.

The measure of BEbot's irony depends on the failure threshold – the more wrong answers users give the more biting lines they get from BEbot. BEbot is intended to appear impatient and self-sure, appreciating quick thinking and high level of preparedness. For correct answers and students' excellence BEbot shares links to amusing or captivating online content. For tardiness and poor performance BEbot shares links to instructional learning material on the specific theme which is going to be tested within the next chat session with BEbot. Whatever the case, both BEbot's appraisal and criticism lead to extension of introduced English language content. Students also like arguing with BEbot, because the set of phrases for leading discussions includes



Figure 1. Screenshot of the BEbot menu and submenus.

cited phrases from several famous classic films and currently popular English and American series.

There are also patterns for specifying counterparts' query, apologizing for being sarcastic and for misunderstanding, patterns encouraging new and profound chats, a small talk set of phrases. All these patterns are a blend from young adult slang and work style phrases, since the working environment of computer specialists is mostly informal. Chatting to BEbot, students learn the patterns and pieces of phrases useful for their communication in English with peers in their office and clients.

In order to define if chatbot inclusion in the Business English course mentioned above

Table 2. Themes of the Business English course.

Theme	Vocabulary/Samples	Grammar	Culture fit aspect
Acquaintance	Introducing oneself and the enterprise one represents. 3 business card samples.	Past Simple; Present Perfect; Polite questions; Question tags	Peculiarities of introducing people in European, South American and Asian countries; small talk.
English for Engineers	Command of language; language skills; ESP. 2 ESP and 2 Business English certificate samples.	Talking about purpose; Future Simple; going to + Infinitive; Present continuous for describing future plans	English as a means of professional communication worldwide
Résumé	Biography; study; career; acronyms. 8 resume samples.	Past Simple; Present Perfect; Passive Voice.	Differences in résumé layouts for specific professional fields; various working environments.
Job Interview	Personal achievements; professional skills; ambitions; 2 interview questionnaire samples; 3 brainteaser samples.	Past Simple; Present Perfect; Present Perfect Continuous; Conditionals; Future Simple; going to + Infinitive; the verb+preposition construction; double object verb formations	Peculiarities of interviewing employees in different professional fields; advantageous behaviour; dress code.

enhanced the students' learning outcomes and if it is the case to what extent, the tests of experiment and control group have been carried out. The group majoring in computer science (the group counts 23 students, the average academic performance is 82 percent) was given the task to use their textbooks, the distant Business English learning course and to spend at least 1 hour a week learning with a chatbot. The group majoring in engineering (21 students, the average academic performance of the group is 85 percent) used only the Business English textbook and the distant learning course. The exit tests of the experimental group have shown that the experimental group results have been 17 percent higher than the results of the control group. Additionally, the computer science students have had a survey about their experience in learning with the chatbot assistance. 98 percent of students have at least once used a chatbot. 79 percent of all responders have previously used English language chatbot applications (figure 2). 82 percent of the group have estimated BEbot as an advanced and efficient chatbot. The responders have distinguished BEbot's personality and maturity, its comprehensible menu and structure following and reflecting the Business English syllabus, and emphasized the chatbot's

Table 3. Phrase samples for some chatbot reactions.

Appraisal	Scolding	Pressing for an answer	Speaking about BEbot
Will never You're a peach! You are quick-witted! Straight Quite I would give anything to hug you! Precisely! High That's just it! Good thinking!	wonders cease! My heart goes out to the teachers who taught you English! A! You failed to prepare yourself for such a trying talk! You need to re-think your attitude toward Business English course! Next time, think for a moment before answering, please.	You're kidding, aren't you? Who taught you how to type? You are temporizing with me! Am I going too fast? What takes you so long? You're making me feel useless now!	I know I am ohmy-godable! Yes, I am cheeky! Sorry, I am up to my neck in work. You will never tire of chatting/learning with me. Being perfect all the time is not taught at school.

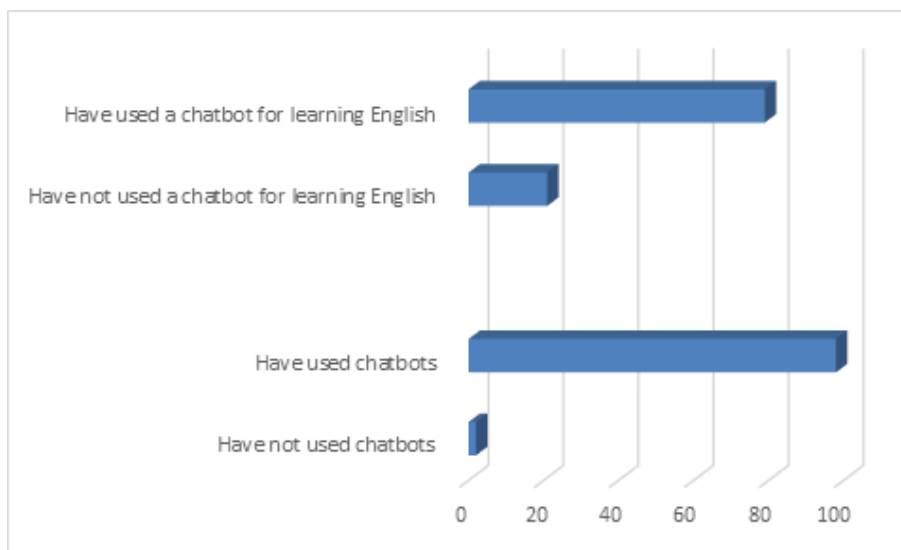


Figure 2. The experience of undergraduates in using chatbots.

user-friendly interface. The user statistics demonstrate that 24 percent of students regularly use BEbot in order to revise grammar and to chat with the ironic partner (figure 3).

BEbot has been demanded by the undergraduates who appreciate the possibility to drill conversational patterns in Business English. The most actively used are not the themes available on other platforms or on the Internet (like Job interview or Acquaintance) but less common aspects which need both language skills and cultural awareness (Communicating across cultures) or, for instance, command of business writing style or delivering presentations in a businesslike

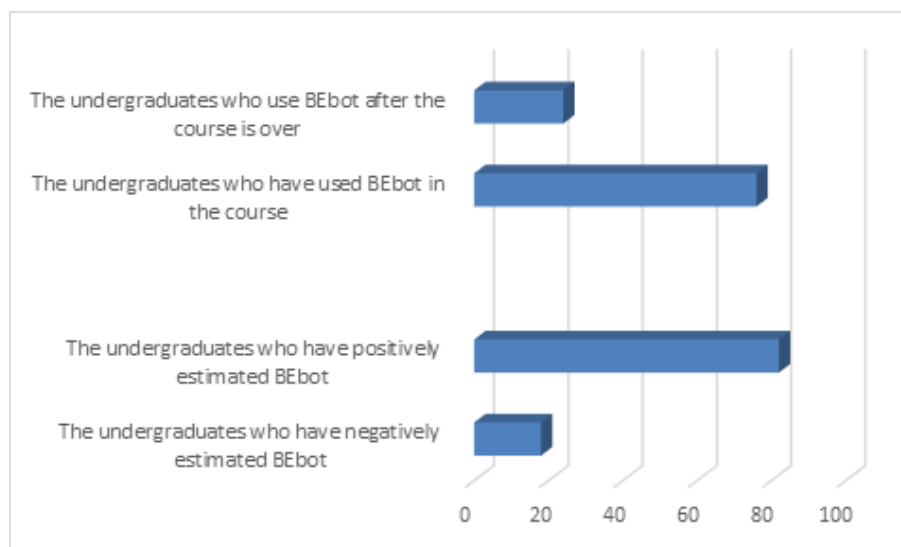


Figure 3. The BEbot user experience and estimation.

manner.

We can suggest that the factors for successful language chatbot implementation are:

- the transparent learning scheme and material structure;
- the rich diversity of additional materials and links;
- the up-to-dateness of the vocabulary revised and learned and of the provided document samples;
- the presence of the chatbot personality;
- the accordance of the chatbot communication style with the approximate age of potential learners and appropriate maturity level.

5. Conclusions

The chatbots are a very efficient learning tool, which have proved demanded by users whose goal is to improve their conversational skills in their second language. The existing chatbot applications have been highly estimated by the researchers, the highlighted beneficial features have been focused on when the Business English chatbot has been created. Some applications and platforms have removed their chatbots due to the enormous amount of resources taken up for the creators to keep supporting AI chatbots. Nevertheless, the actual source analysis confirms that chatbot efficiency is undoubted and language teachers' interest in their application has been constantly increasing. The previous experience of the undergraduates in using chatbots for learning has been taken into consideration, too.

The designed in Telegram and introduced within the Business English course chatbot BEbot has been tested and afterwards actively used by the undergraduates. Along with developing business-like communication skills, language-in-use skills, cultural distinction knowledge, command of business writing style and delivering presentations in a businesslike manner are inculcated in learners through communication with BEbot. The users have estimated it as a comprehensible, user-friendly and efficient tool not only for practicing the prescribed syllabus tasks along with the coursebook activities but also for drilling and reviewing specific vocabulary and grammar aspects after the Business English course completion.

Adding voice input and voice recognition function is being considered. Another design prospect is creating a Business English chatbot based on the use-proved content and aspect

set of BEbot using Python which allows to broaden user friendliness, and to refine chatbot's conversational manner.

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Application of artificial intelligence in higher education institutions for developing soft skills of future specialists in the sphere of information technology

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The poster features a dark blue background with a green circular graphic on the left containing the text 'ECS UNITED' and a stylized 'E' with three vertical bars. The ECS logo is in the top right, followed by the society's name and tagline. Meeting details are listed in the center right, and a call to action is at the bottom left. A green circle in the bottom right contains the abstract deadline.

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Application of artificial intelligence in higher education institutions for developing soft skills of future specialists in the sphere of information technology

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Abstract. This paper aims to delineate the significant role of artificial intelligence (AI) in developing the soft skills of future information technology (IT) professionals. To achieve this goal, the authors give some relevant considerations concerning using AI in teaching humanitarian subjects and explore the use of AI to develop soft skills essential for future IT professionals. First, the analysis of the survey results confirms that students are not aware that using AI in education is very helpful. That is why many students (51.8%) do not use them at all. Therefore, we have an intention to give the examples of the use of AI tools for educational purposes to equip students, first of all, with understanding of soft skills value, and, secondly, let them complete the tasks that contribute to the development and improvement of their soft skills. Second, we defined that the soft skills (communication, negotiation, problem-solving, finding a common language with colleagues and clients, public speaking, and intercultural) are essential for conducting professional communication with colleagues in the sphere of IT to satisfy the demands of the IT industry in the modern-day world. Third, the paper contributes scientifically to investigating the integration of AI technologies in the university-level educational landscape. Integrating AI in higher education institutions offers a promising route for developing or boosting the soft skills necessary for future specialists in the field of IT. Drawing on a comprehensive review of literature focusing on the use of AI technologies in the contemporary world and considering the empirical data from the online survey, the study investigates the opportunities of AI tools to foster soft skills required to achieve the active collaboration of IT employees for companies.

1. Introduction

1.1. The most relevant data considering the world experience of applying AI

Artificial intelligence (AI) is changing our society. AI also changes the way we learn, research, or work. AI accompanies us everywhere, wherever we are in the contemporary world. Nowadays, we have a lot of AI tools that can help us with various tasks and challenges. Currently, the number of AI tools is more than 5 304 [1], or even more; their number reaches from 5 619 [2] to 10 245 AI tools [3]. The capabilities of AI tools are becoming more and more diverse. As proof,



we give the following fact: In March 2023, the responsible experts registered 271 new capabilities for the current year. We noted that new and unique capabilities appeared every month. Notably, in December of the current year, in 2023, these were the following AI tools: descriptive navigation (<https://aimaps.app>), personalized Santa videos (<https://www.santaknowsyou.com>), Arduino code generation (<https://www.pleasedontcode.com>), agents (<https://www.monoid.so>), government contracts (<https://www.bidlytics.co>), call bots (<https://adola.ai>), live captions (<https://line-21.com>), cross-platform communication (<https://www.drift.com>), outfit feedback (<https://www.myfitchecker.com>), screen recordings (<https://www.screenstory.io>).

Besides, the quantity of scientific articles that shed light on AI is constantly growing. Researchers from around the world delve into areas of applying AI. So, as Figure 1 illustrates, from 2010 to 2021, the total number of publications related to AI increased twice, from 200,000 in 2010 to almost 500,000 in 2021.

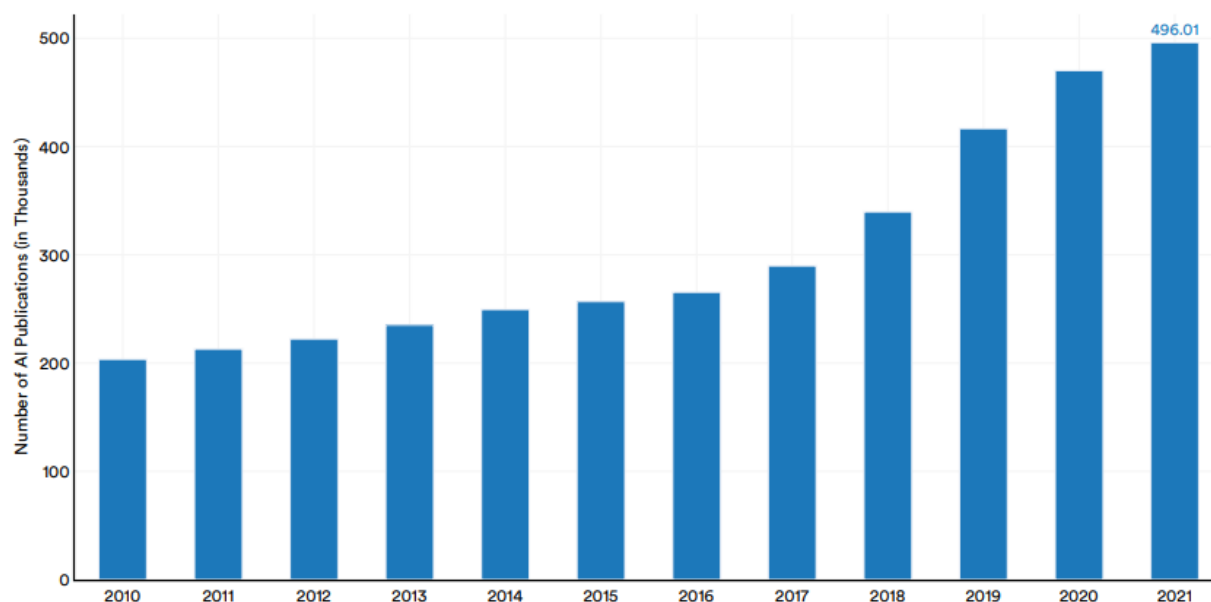


Figure 1. The quantity of scientific publications about AI from 2010 to 2021: the scale of world science [4].

1.2. Using AI in education

Today, higher education has experienced the incorporation of AI tools in learning and teaching. In our view, it is not a surprise for all, as in modern reality, “AI in education refers to the integration of AI into the educational practices to ensure that the entire learning process is effectively supported” [5]. Most likely, this is not a minor reason; it is a matter of understanding why teachers use AI tools to teach future specialists in the sphere of IT at higher education institutions. Let us note some relevant aspects in this context. We consider that pedagogues mainly use AI tools to develop students’ hard skills, but in our view, developing soft skills is also essential. Humanities disciplines, predominantly English, play a leading role in this process. In this context, we note that “AI may be beneficial for language teaching and learning for a series of reasons, including the fact that it can support the learning of vocabulary and grammar, improve students’ skills such as problem-solving and collaboration, provide real communicative situations, save time for teachers, and offer personalization, adaptability, and flexibility, among others” [6].

Noteworthy of mention is that in the contemporary landscape of higher education, training future specialists with a major in IT includes the teaching approaches (the symbolic “top-down” approach and the connectionist “bottom-up” approach) that imply the usage of AI and related instruments. These AI instruments serve as resources for improving technical knowledge and technical/hard skills. We also would like to mention that the development of the hard skills (the hard skills: programming languages, database management, statistical analysis, storage systems, and management) of future IT specialists is essential. These skills are valuable for conducting work in the IT sphere. Students can demonstrate their proficiency in hard skills via relevant skill assessment tests and their ability to work in the IT sphere. However, alongside the development of hard skills, the development of soft skills arises as an equally essential aspect within the training of IT specialists at the university level. Let us mention that the study of humanitarian disciplines at universities contributes to the development of soft skills for future IT professionals and promotes a successful career path.

While technical understanding (hard skills) remains essential for IT professionals, the evolving requirements of the modern-day labor market to specialists emphasize the indispensability of having and improving soft skills. And that is why, humanitarian subjects, particularly the study of a foreign language, are primary contributors to soft skills development, ensuring the wellrounded training of future IT specialists.

2. Literature review on the AI application in modern-day life

To observe the scope of AI applications, we focus on articles that reveal AI’s use for developing soft skills. In line with this intention, we have taken into consideration the fact that given the increased importance of AI in the modern-day period, there are AI tools and various applications that pedagogues can apply to develop soft skills for specialists of different specialties [7]. There is an apparent demand to obtain soft skills in technologically driven spheres. Professional collaboration requires soft skills such as critical thinking, problem-solving, communication skills, and creativity with flexibility [8]. Vidal et al. [9] consider the methodology that addresses obtaining soft skills by future specialists in the computer technology sphere. Scholars emphasize the need to incorporate AI capabilities in curriculums to improve or develop students’ critical thinking and problem-solving abilities, support independent learning, and help educators design curriculums effectively [10].

Moreover, some works describe the experience of using AI in teaching English. Briguglio associate studying English with forming soft skills [11]. In this context, it is essential to note that currently, there are automatic speech recognition (ASR) technologies (use of machine learning or AI technology to process human speech into readable text) that can facilitate the improvement in pronunciation to a more considerable extent than human teachers can and, because of constant improvements of this technology, ASR programs have great potential in foreign language learning [12]. Researchers consider ChatGPT to support language learning and the development of linguistic and social skills [13].

Additionally, we noticed that in a systematic review of scientific studies on the use of AI in teaching and learning English, Sharadgah and Sa’di [5] made the following conclusions: first, AI in English language teaching yielded positive results in terms of optimizing English language skills, translation, assessment, recognition, attitude, satisfaction; second, AI technologies make it possible to make the learning process more differentiated, promote a wide choice of students; many new systems for language learning using AI appear daily; third, now teachers apply various approaches evolving AI technologies for language learning, including machine learning, neural network, support vector machine, genetic algorithms, deep learning, decision tree, expert system, natural language processing, data mining, cloud computing, and edge computing. Scholars confirm the idea and our belief that the pedagogues are optimistic about the potential of AI-assisted language learning (AIALL) for teaching and learning languages. However, they feel a

certain anxiety regardless of their context. Besides, the scientists approve that teacher training is essential to introduce AIALL in the classroom and that practitioners need to rethink assessment to avoid plagiarism and cheating, but also to take advantage of AIALL [6].

This path of using AI in English language teaching is still in its infancy and hardly moves from the initial point. In this regard, there is a need to investigate the use of AI tools and to develop the soft skills of future professionals in the IT sphere.

Researchers recognize that the landscape of IT has dramatically transformed with the onset of AI and many AI tools, and they are now widespread in education. These tools have flooded almost every sector, not only an educational one, and consequently change how we live, work, and interact. AI tools are used in healthcare to predict diseases [14]. They help during surgical operations [15]. They accurately and quickly diagnose diseases [16].

It is worth noting that business people use AI tools to do big data analytics, automatize routine statistic tasks, and satisfy their customers' demands [17,18]. People use AI tools in the entertainment industry for audio, image, and video analysis, gaming, journalism, script writing, filmmaking, social media analysis, and marketing [19]. Citizens, researchers, and employees use AI tools in the transportation sector to optimize routes, predict maintenance needs, and develop autonomous vehicles [20–22].

The materials analyzed and presented above confirm that AI spreads in almost all spheres of modern-day life. The area in which AI is expected to have the most significant impact is education; it will promote a new twist in teaching and learning [23]. At the present stage, in the education sector, pedagogues use AI tools in education to support active self-regulated learning [24], personalized [25], blended [26], and adaptive learning formats [27]. AI tools help educators tailor and satisfy each learner's needs, enhancing special education's learning process [28].

Delving into the theme of the application of AI in education, it is relevant to mention that teachers perceive AI as a whole with various educational technology platforms such as virtual mentors, voice assistants (Google Assistant, Siri, Cortana), smart content, presentation translator, global courses (Udemy, Google AI, Alison, Khan Academy, edX, Udacity, Coursera, etc.), automatic assessment, personalized learning (Ruangguru, etc.), educational games, the intelligent tutoring system or intelligent computer-aided instruction [29].

Today, the professional training of IT specialists is only complete with AI tools [30]. The AI tools are applicable for solving programming problems [31], improving the code completion strategy [32], intelligent Python language teaching [33], mathematical training [34], assisting novice programmers [35].

The quick advancement of AI covers all spheres of life activity, everyday life, and education. Notably, as the literature review on the application of AI in modern-day life shows, educators and researchers devote much time to investigating AI-related issues. They delve into the topic of using AI tools in the professional training of future IT specialists. In their scientific papers, the researchers investigate and analyze approaches to forming hard skills (programming, mathematical) in teaching. It is a well-known fact that soft skills are also crucial in the future professional activity of IT specialists. Therefore, we focus on AI and consider its applicability in developing and improving the soft skills of future IT specialists.

3. Theoretical background

3.1. The definition of the term “artificial intelligence”, abbreviated as AI. Key benefits of AI
The term defines the meaning of the abbreviation AI and the expression “artificial intelligence”, a layman associates with describing the simulation of human intelligence processes by machines or computers. A key benefit of AI is its ability to make a difference in all spheres of human lives. Note that “AI provides a huge imagination space for future life, and education is considered as one of the best application scenarios of AI landing” [36]. Fraud detection, customer service work,

quality control, and lead generation are some of the tasks that technology effectively automates.

AI can be beneficial. AI can benefit learning English in the educational environment in nonlinguistic departments. As AI continues to develop, more and more tools people know. These AI tools are available, and they help people learn English. There are many ways that people can use to improve their English skills (reading, writing, speaking, listening) with AI.

In particular, we draw attention to chatbots, which are becoming increasingly popular. Scientists refer to “chatbots” as “conversational agents”. They allow for human-computer interaction using the technology’s natural learning processing abilities that provide information via interactive methods [37, 38].

There are 3 major components of chatbots [37]:

- chatbots are inclined to simulate human speech [39];
- chatbots interact with and relate to messages [40];
- chatbots do not have a physical presence [41].

3.2. What are the tools of AI? Classification of the AI tools

AI tools are applications or systems that use AI techniques, including machine learning, deep learning, natural language generation, speech recognition, biometrics, and more, to complete tasks that usually require human intelligence or creativity [42]. In our time, we have a lot of AI tools that can help us with various tasks and challenges. The company “Sequoia Capital” offered the document entitled ‘Generative AI: A Creative New World’ – ‘The Generation AI Application Landscape’ (for short: Landscape). This document – Landscape – deals with and describes the domains of use of generative AI (text, code, image, speech, video, 3D, and other), the functions that applications perform separately for each category at the applications level, and the models on which they are based. These models are based on an infographic designed by Richie Cotton for the online learning company Data Camp [43]. The document “Landscape” involves information on text, image, video, audio, coding, the daft application, bots, and other applications. For example, text applications that are used for the following purposes: first, to search on the Internet (Andi, Microsoft new Bing); second, in the sphere of enterprise, sales, marketing, and accounting (ExactBuyer, Glean, Hebbia); for jobs (Apply AI, hireBrain, JobHuntMode); for books, images, podcasts, videos and TV (All Search, Anypod, EveryPixel); for research purposes (AlphaResearch, Elicit, NewsDeck); for code (bloop, GitHub Data Explore); second, to chat (OpenAI ChatGPT, Google Bard, Claud); third, to sales and marketing copy generation (anyword, copy.ai, copymatic, Creatext); fourth, to e-mail generation (Autobound, Benchmark, HyperType); fifth, to note-taking and document summarization (Cogram, genei, Hila); sixth, writing assistance and translation (WordTune, git18n, Grammarly).

These are just some of the many AI tools available today. Earlier this year, 2024, more and more AI tools are being developed daily. AI tools help enhance our productivity, creativity, and knowledge and solve some of the most complex problems in the professional training of future IT specialists.

3.3. The practical aspects of using AI instruments in soft skills development within the preparation of future IT specialists

Soft skills are essential in the preparation of future IT professionals. Scientists think communication, collaboration, and problem-solving are among the most demanded soft skills in IT job opportunities [44]. Diwan, Waite, and Jackson considered the importance of group work skills, including negotiation skills, in preparation for students in computer science [45]. Also, Sumaiya et al. identify an essential skill as building personal relationships with team members to provide a feeling of connection, harmony, and an everyday basis for successful outcomes and desired results [46]. As a result of the professional training of future IT

specialists, higher education institutions can promote students' employability skills, including intercultural communicative competence and foreign language skills for effective communication in international working environments. Also, Li et al. [47] and Briguglio [11] focus on indicating that developing intercultural communication skills can help IT professionals find a common language with colleagues and clients from diverse backgrounds.

So, based on the analysis of scientific publications on the soft skills of future IT specialists, we can name the soft skills that pedagogues can develop using AI tools, namely communication, negotiation, problem-solving, the ability to find a common language with colleagues, and clients, public speaking, and intercultural skills. For future IT specialists to form these skills using AI tools, we suggest using prompts in Microsoft Copilot (before Bing Chat).

4. Materials and methods

4.1. *Methods, data collection tools and procedures*

The study is a descriptive (description of the experience of using AI in education), qualitative (literature analysis), and quantitative (questionnaire) study, using the data that the authors took from the analysis of the survey conducted at non-linguistic higher schools. We surveyed students in Bratislava, Slovakia, during the fall semester 2023. We compiled survey data from 24 November 2023 to 12 December 2023. Data collection involved an online survey in Google Forms comprised of 5 questions (appendix A). When compiling the questionnaire, we used the recent scientific research findings of Dakakni and Safa [48]. Participants, 110 young people, are bachelor's students of non-linguistic higher education institutions – first-year students (89.1%) and second-year students (10.9%).

4.2. *The aim, objectives, and the research questions of the study*

Our scientific research aims to clarify the role of soft skills for students who majored in IT. We consider using AI tools in teaching humanitarian subjects in the educational process.

We stated the following research questions (RQ):

- RQ 1.** Are AI tools used to build the soft skills of future professionals in IT? What is the experience of using them?
- RQ 2.** What AI tools can the teacher use to develop the soft skills of IT professionals in learning English?
- RQ 3.** Can AI technologies contribute to developing soft skills in English language learning? How?

To answer these questions, we set the following objectives:

- to analyze the experience of using AI to develop soft skills, in particular in the professional training of future IT specialists;
- to identify specific AI tools used to develop soft skills when future IT professionals learn English;
- to offer examples of using AI tools to develop the soft skills of future IT specialists in learning English.

5. Results

5.1. *Descriptive findings from the online survey*

In line with the second research question, "What AI tools can be used to build the soft skills of IT professionals in the process of learning English?", the answers of students to the proposed questions were considered (appendix A and appendix B).

The analysis of students' answers to the Q1 of the questionnaire – “Which tools (of those listed below) do you use most frequently in learning English as a foreign language” – approximately 51.8% do not use these tools, 29.1% favoured Chat GPT, 9.1 – Grammarly, 3.6% – Bing (Microsoft Copilot), 2.7% – Quillbot in addition to Chat GPT, 1.8% – Bard (Gemini), 0.9% – Assistant Poe, 0.9% - Quillbot.

In order to reveal the purpose of AI use, Q2 – “What are the reasons for using AI tools?” – was proposed. It was disclosed that the primary reason is that AI tools give students ideas for their study of English. Note, that 16.4% of respondents chose this option. Approximately the same number of respondents think that AI tools support their intention to learn the English language, respectively 11.8% of respondents confirmed it, and that AI tools help to maintain high grades by getting creative ideas to help with their assignments and essays, 10.9% of respondents think so. And, 9.1% hold the view that AI tools add more style and technique to their writing in English.

Attitudes towards AI we found out by means of analyzing the answers to two questions. So, let us look at these questions. Answering Q3 – “What is your opinion on AI tools and their use in learning English?” – students, namely 78.2%, noted that AI tools are beneficial. Answering Q4 – “Would you prefer to be taught the English language using AI teacher bots or human teachers?” – the vast majority of the respondents, namely 87.3%, noted that they prefer a human teacher.

The issue related to AI and ethical concerns is of great relevance today. It was noted that opinions on this matter divided equally.

To illustrate the usefulness of AI tools in the professional IT sphere, we propose IT students to complete a range of tasks that involve the professional situation that are real at work. So, students use IT and understand the benefits of applying them in work-related situations.

5.2. Tasks for developing soft skills of future professionals in IT sphere

To form communication skills, you can invite students to ask Microsoft Copilot tasks to write a negotiation plan on creating an online store site or an interview question. Such tasks will provide students with examples based on which they can develop their plan/strategy or scenario of communication with the customer regarding the development of a particular software product or prepare for an interview.

Task 1. Develop a plan (scenario) of communication with the customer regarding the development of a specific software product.

Prompt in Microsoft Copilot (Style “More Balanced”): Write a plan for negotiations regarding the creation of an online store website. Let us present 1 of 30 responses.

Answer Microsoft Copilot: To create a plan for negotiations regarding the creation of an online store website, you can follow these steps:

1. **Define the scope of the project:** Determine the goals and objectives of the website, the target audience, and the features that the website should have. This will help you to identify the resources that you need and the budget required for the project.
2. **Research the market:** Conduct market research to identify the competition, the trends, and the best practices in the industry. This will help you to identify the unique selling points of your website and to differentiate it from the competition.
3. **Identify the stakeholders:** Identify the stakeholders involved in the project, including the decision-makers, the project team, and the vendors. This will help you to establish clear lines of communication and to ensure that everyone is on the same page.
4. **Develop a project plan:** Develop a project plan that outlines the timeline, the milestones, and the deliverables of the project. This will help you to manage the project effectively and to ensure that it is completed on time and within budget.

5. **Define the roles and responsibilities:** Define the roles and responsibilities of each member of the project team. This will help you to ensure that everyone knows what is expected of them and that there is no confusion or overlap.
6. **Establish the budget:** Establish the budget for the project and allocate the resources accordingly. This will help you to ensure that the project is completed within the budget and that there are no unexpected costs.
7. **Negotiate the terms:** Negotiate the terms of the project with the stakeholders, including the scope, the timeline, the budget, and the deliverables. This will help you to ensure that everyone is on the same page and that there are no misunderstandings.
8. **Monitor the progress:** Monitor the progress of the project and make adjustments as necessary. This will help you to ensure that the project is completed on time and within budget.

Task 2. To prepare for an interview at an IT company for the position of Python programmer.

Prompt in Microsoft Copilot (Style “More Balanced”): I am a beginner programmer. I need to prepare for an interview at an IT company for the position of Python programmer. Suggest me the questions that can be asked to me at the interview.

Answer Microsoft Copilot: Sure, here are some common Python interview questions that you might find helpful:

1. What is Python? What are the benefits of using Python?
2. What is the difference between a list and a tuple in Python?
3. What is the difference between a set and a dictionary in Python?
4. What is the difference between a module and a package in Python?
5. What is the difference between a local variable and a global variable in Python?
6. What is the difference between a class and an object in Python?
7. What is the difference between a method and a function in Python?
8. What is the difference between a static method and a class method in Python?
9. What is the difference between a decorator and a generator in Python?
10. What is the difference between a deep copy and a shallow copy in Python?

To form negotiation skills, you can invite students to set Microsoft Copilot tasks to write an example of negotiations between the customer and the programmer on software product development, project tasks, etc. Such a task will allow students to get an example, based on which they will gain an understanding of the principles of negotiating with clients, and therefore will be able to develop negotiation skills.

Task 3. Prepare for negotiations with the customer or client.

Prompt in Microsoft Copilot (Style “More Balanced”): Write an example of negotiations between a customer and a web programmer regarding the creation of a web site for an online store.

Answer Microsoft Copilot: Here is an example of a negotiation between a customer and a web programmer regarding the creation of a website for an online store:

Customer: Hi, I'm interested in creating an online store website. Can you help me with that?

Web Programmer: Sure, I'd be happy to help. What are your requirements for the website?

Customer: I want a website that is easy to navigate, has a clean design, and is optimized for search engines. I also want to be able to accept payments online and manage my inventory.

Web Programmer: Great, those are all important features for an online store. Do you have any specific design or branding requirements?

Customer: Yes, I want the website to reflect my brand and be consistent with my other marketing materials.

Web Programmer: Understood. Based on your requirements, I estimate that the project will take about 3 months to complete and will cost around \$10,000. Does that work for you?

Customer: That sounds reasonable. Can you provide a detailed project plan and timeline?

Web Programmer: Absolutely. I'll put together a project plan that outlines the timeline, milestones, and deliverables of the project. I'll also include a breakdown of the costs and resources required.

Customer: Sounds good. Can we also discuss the terms of the contract?

Web Programmer: Of course. I'll prepare a contract that outlines the scope of the project, the timeline, the budget, and the deliverables. I'll also include a section on intellectual property rights and confidentiality.

Customer: That sounds good. Let's move forward with the project.

Web Programmer: Great, I'm looking forward to working with you.

To form problem-solving skills, you can invite students to set Microsoft Copilot tasks based on the described problem situation to offer a way to solve it and provide recommendations for its elimination. Such a task will allow students to get an example, based on which they will understand how to solve problems in a working city and, therefore, will be able to develop problem-solving skills.

Task 4: Learn how to solve issues at work by communicating with colleagues, team, and employers.

Prompt in Microsoft Copilot (Style "More Balanced"): You are a programmer. You work in an IT company. You feel that you are not trusted as a specialist in the company. After all, you are asked to write a list of tasks that, in your opinion, need to be done, but the customer did not allocate time for this. How to solve this problematic situation?

Answer Microsoft Copilot: You are a programmer. You work in an IT company. You feel that you are not trusted as a specialist in the company. After all, you are asked to write a list of tasks that, in your opinion, need to be done, but the customer did not allocate time for this. How to solve this problematic situation?

It can be frustrating to feel like you're not trusted as a specialist in your company. Here are some steps you can take to address the situation:

- 1 **Communicate your concerns:** Schedule a meeting with your manager or supervisor to discuss your concerns. Explain that you feel like you're not being trusted as a specialist and that you're being asked to do tasks that aren't feasible given the time constraints.
- 2 **Provide evidence:** Back up your concerns with evidence. Show examples of tasks that you've been asked to do that are outside the scope of your role or that require more time than you've been given.
- 3 **Propose solutions:** Offer solutions to the problem. For example, you could suggest that the company hire additional staff to help with the workload, or that the scope of the project be adjusted to better align with the available resources.
- 4 **Be open to feedback:** Be open to feedback from your manager or supervisor. They may have insights or suggestions that you haven't considered.
- 5 **Focus on building trust:** Focus on building trust with your colleagues and superiors. Be reliable, communicate effectively, and follow through on your commitments. Over time, you can demonstrate your expertise and build a reputation as a trusted specialist in your field.

To improve the ability to find a common language with colleagues and the client, you can invite students to set Microsoft Copilot tasks based on the described situation to provide advice on communication. Performing this task in an English class will allow students to get an example through which they gain an understanding of how to find a common language with colleagues and clients in the process of future professional activity, and therefore will be able to develop this skill.

Task 5: Learn to find a common language with colleagues and the client.

Prompt in Microsoft Copilot (Style “More Balanced”): You work in an IT company. Your customer is not happy that their order is taking too long. That you suggested that I answer him?

Answer Microsoft Copilot: You work in an IT company. Your customer is not happy that their order is taking too long. That you suggested that I answer him?

If a customer is unhappy about a delayed order, it's important to respond promptly and professionally. Here are some tips on how to respond to a customer complaint about delivery delay:

- 1 **Acknowledge the issue:** Start by acknowledging the customer's complaint and apologizing for the delay. This shows that you take their concerns seriously and are committed to resolving the issue.
- 2 **Explain the situation:** Provide an explanation for the delay, such as a backlog of orders or a shipping delay. Be honest and transparent about the situation, and avoid making excuses or blaming others.
- 3 **Offer a solution:** Offer a solution to the problem, such as a refund, a discount on a future purchase, or expedited shipping. Make sure that the solution is appropriate for the situation and that it addresses the customer's concerns.
- 4 **Follow up:** Follow up with the customer to ensure that the issue has been resolved to their satisfaction. This shows that you value their business and are committed to providing excellent customer service.

Here's an example of how you could respond to the customer:

Dear [Customer Name],

Thank you for bringing this to our attention. We apologize for the delay in your order and understand how frustrating this must be for you.

We experienced an unexpected backlog of orders due to a recent sale, which caused a delay in processing and shipping your order. We are working hard to get your order to you as soon as possible and appreciate your patience.

To make up for the delay, we would like to offer you a [refund/discount on a future purchase/expedited shipping]. Please let us know which option you prefer.

Again, we apologize for any inconvenience this has caused and appreciate your business. If you have any further questions or concerns, please don't hesitate to contact us.

Best regards, [Your Name]

To improve intercultural skills while learning English, future IT professionals can set the task of Microsoft Copilot to write tips on behavior during negotiations with international testators. Such a task will allow students to gain an understanding of another culture, based on which they will form intercultural skills.

Task 6: Get information on the numbers and conventions of representatives of other nationalities.

Prompt in Microsoft Copilot (Style “More Balanced”): I work in a Norwegian IT company. We plan to do a joint project with Chinese colleagues. I know we have cultural differences.

What would you advise me to do when I meet colleagues from China for the first time so that I don't seem rude?

Answer Microsoft Copilot: I work in a Norwegian IT company. We plan to do a joint project with Chinese colleagues. I know we have cultural differences. What would you advise me to do when I meet colleagues from China for the first time so that I don't seem rude?

It's great that you're thinking about how to approach your Chinese colleagues in a culturally sensitive way. Here are some tips that might be helpful:

- 1 **Be respectful:** Show respect for your colleagues by using their formal titles and last names, unless they ask you to use their first name. In Chinese culture, it's important to show respect for authority and seniority.
- 2 **Be patient:** Be patient when communicating with your Chinese colleagues. They may take longer to respond or may not be as direct as you're used to. This is because Chinese culture values harmony and avoiding conflict.
- 3 **Be aware of body language:** Be aware of your body language when communicating with your Chinese colleagues. Avoid pointing, touching, or standing too close, as these actions can be seen as aggressive or rude.
- 4 **Avoid sensitive topics:** Avoid discussing sensitive topics such as politics, religion, or human rights. These topics can be seen as controversial or offensive.
- 5 **Be open-minded:** Be open-minded and willing to learn about Chinese culture. Ask questions and show interest in your colleagues' culture and traditions.
- 6 **Be flexible:** Be flexible and willing to adapt to your colleagues' communication style. This will help you to build stronger relationships and work more effectively together.
- 7 **Take advantage of team building activities:** Take advantage of team building activities, birthdays, or other activities outside the office as a more informal way of connecting with your colleagues. This can help to build trust and rapport.

5.3. Five best AI tools for public speaking

In the realm of AI, the application of AI tools in public speaking marks a significant advancement. These tools offer practical solutions for enhancing speaking skills, addressing common challenges faced by speakers at all levels. By leveraging AI technology, these tools provide valuable insights into speech delivery, content organization, and audience engagement. Our exploration of some of the best AI public speaking tools will introduce a range of innovative platforms designed to improve various aspects of public speaking: Yoodli; Verble; Gabble; Virtual Orator; Orai. To improve public speaking skills in the profession of learning English, you can invite students to take advantage of a number of innovative platforms designed to improve various aspects of public speaking [49] namely:

1. Yoodli – an AI-driven public speaking coach that provides real-time feedback and analytics on speech delivery, style, and audience settings.
2. Verble – an AI speech-writing assistant that helps users craft persuasive and structured speeches through a chat-based interface and expert insights.
3. Gabble – an AI-powered communication coach that focuses on improving speaking and listening skills, offering personalized feedback and vocabulary enhancement.
4. Virtual Orator – VR simulator that replicates realistic public speaking scenarios, allowing users to practice in front of virtual audiences and record their performances.
5. Orai – an AI-powered app that offers interactive lessons and detailed speech analysis, aiming to boost confidence, clarity, and voice quality in public speaking.

Therefore, based on the proposed examples of using such an AI tool as Microsoft Copilot, it can be stated that AI tools can be used to form the soft skills of future IT specialists while learning English. In particular for the formation of such skills as communication, negotiation, problem solving, ability to find a common language with colleagues and clients, public speaking and intercultural.

6. Conclusions

As technological advancements continue to shape the landscape of education, there is growing recognition of AI tools' role in developing vital soft skills for IT students. As achieving the objectives set in this study allows us to equip pedagogues of higher education institutions with actionable tactics to direct students' efforts toward harnessing appropriate skills, we delved into the transformative potential of AI tools in developing the soft skills essential for the success of future IT professionals. For this, we stated three research questions, the answers to which we obtained in the process of the research in the following scope:

- (RQ 1). Artificial intelligence tools or tools with elements of artificial intelligence are used to develop communication skills in training future IT professionals. In particular, AI tools are used for developing critical thinking, problem-solving, communication skills, creativity, flexibility, and independent learning.
- (RQ 2). The survey results (appendix B) confirm that AI tools have a noteworthy function in learning English as a foreign language by IT professionals. People acknowledge AI tools as resources that assist in generating ideas and enhancing writing styles. At the same time, students are not confident in the use of AI tools in the learning process. They do not have the appropriate knowledge on how to apply AI to develop soft skills.
- (RQ 3). AI technologies contribute to the development of soft skills in English language learning. To do this, teachers can use the capabilities of chats using generative artificial intelligence technologies. Using the example of Microsoft Copilot, particular prompts were proposed that allow future IT specialists to develop such skills as communication, negotiation, problem-solving, finding a common language with colleagues and clients and intercultural. We also recommend developing public speaking skills using AI tools to improve the ability to communicate in business related themes (Yoodle, Verble, Gabble, Virtual Orator, Orai).

Within the current study, we did not consider all the aspects of using AI in education of future IT specialists. Further research intentions will disclose the effectiveness of applying defined approaches (e.g., tasks with Bing (Microsoft Copilot) or other AI chats, AI tools to improve the ability to communicate) to improve or develop soft skills.

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Appendix A. Questionnaire

The survey was compiled using the research finding of Dakakni and Safa [48].

Types of AI tools

Q1. Which tools (of those listed below) do you use most frequently in learning English as a foreign language?

Response options

- Bing
- Bard
- Microsoft Cortana
- Assistant Poe
- Chartbot GPT
- Grammarly
- Quillbot
- Quillbot in addition to Chat GPT
- none of them

Reasons for using AI tools

Q2. What are the reasons for using AI tools?

Response options

- AI tools support my intention to learn the English language
- AI tools add more style and technique to my writing in English
- AI tools give me ideas for my study of the English language
- AI tools help me maintain high grades by getting creative ideas to help with my assignments or essays
- I do not use AI tools for any reason

Attitudes toward AI

Q3. What is your opinion on AI tools and their use in learning English language?

Response options

- AI tools are beneficial
- I treat AI tools with mistrust and suspicion

Q4. Would you prefer to be taught the English language using AI teacher bots or human teachers?

Response options

- I prefer to have a bot as a teacher of English as a foreign language and replace a human teacher
- I prefer a human teacher

AI and ethical concerns

Q5. Are you concerned about AI ethical issues?

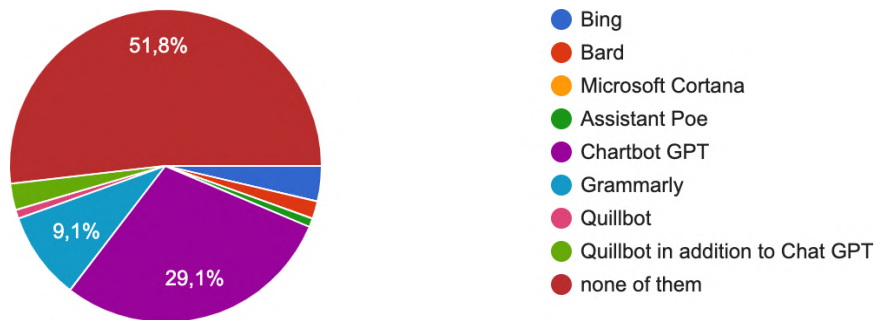
Response options

- Yes, I am. I do not use AI to help complete my assignments, taking into consideration the university's punitive measures
- No, I am not

Appendix B. Questionnaire questions and students' choice

Types of AI tools

Q1. Which tools (of those listed below) do you use most frequently in learning English as a foreign language?



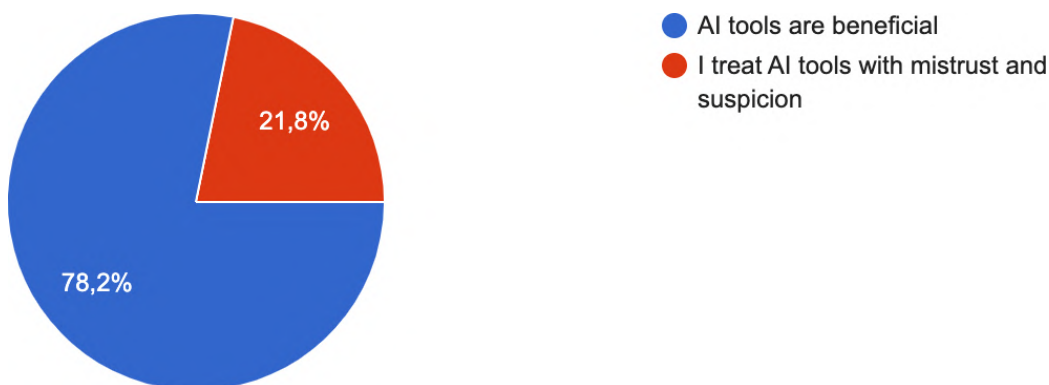
Reasons for using AI tools

Q2. What are the reasons for using AI tools?

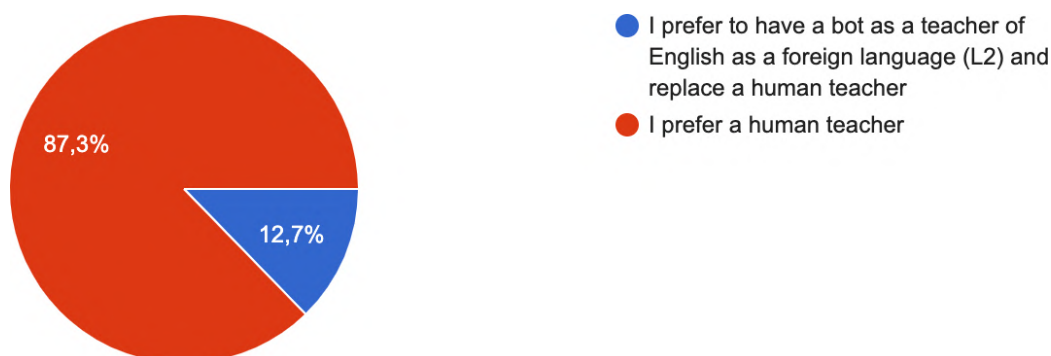


Attitudes toward AI

Q3. What is your opinion on AI tools and their use in learning the English language?

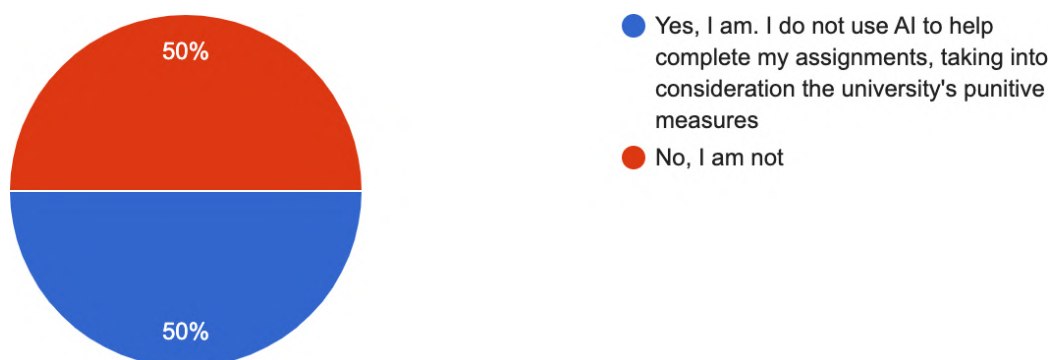


Q4. Would you prefer to be taught the English language using AI teacher bots or human teachers?



AI and ethical concerns

Q5. Are you concerned about AI ethical issues?



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Microlearning technology based on video content: advantages, methodology and quality factors

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Abstract. The quality organization of the educational process using video-based microlearning technology can have several benefits for students. These include the ability to learn at their own pace and according to their individual needs, access from anywhere at any time, and focus on specific topics and tasks, which allows them to better absorb the learning material. Microlearning technology is being used effectively in business for employee training. However, the present study focused on the process of teaching using microlearning technology based on video content within the discipline Information Systems and Technologies in Economics. The experiment involved teachers and students of the National University of Life and Environmental Sciences of Ukraine (NULES). To evaluate the quality of video-based microlearning technology, a data coverage measurement and analysis model (SBM-DEA) was used. The input factors were indicators of the quality of the e-course and learning technology, and the output parameters were students' academic performance, students' and teachers' evaluation of the e-course and learning technology. The results showed that out of 39 respondents, 29 confirmed the effectiveness of this technology, which is 75% of the total. This indicates that the introduction of microlearning technology into the educational process has improved learning outcomes and that this technology has been positively evaluated by both teachers and students. The results of the study are important for improving the quality of organization of the educational process using the technology of microlearning based on video content, identifying key factors of quality of microlearning based on video content.

1. Introduction

The widespread development of distance learning and the introduction of modern educational technologies have significantly changed the approach of teachers to the organization of the educational process and, consequently, of students to the study of educational material, making learning more flexible and adapted to their needs [1,2]. Students of higher education institutions are increasingly dissatisfied with the traditional classroom format of learning, the presentation of theoretical material exclusively in text format, and are looking for alternative ways to acquire knowledge. It is extremely important to choose a technology and a learning model that will contribute to better motivation and satisfaction of students and thus improve the quality of learning. The creation of e-courses based on video content is an important area of development



and delivery of quality education in today's environment [3,4]. According to a study conducted by Pearson [5], video is the most popular format of educational content worldwide. Video content accounts for approximately 60% of the total amount of learning content used in education. Among the various learning technologies, microlearning stands out for its ability to present material to students in short blocks of different types of content. This approach allows students to consolidate their knowledge and skills by working through the e-course materials.

A recent research report found that many professionals considered microlearning to be any learning that takes less than 13 minutes to consume, with segments of between 2 to 5 minutes as most favorable. Due to the smaller size and length of content, microlearning allows them to very quickly iterate and deliver material to their target audience. This allows them to provide more relevant content that meets the immediate needs of the learners. It also means that end users experience a shorter wait time for content and can start training on new topics quickly [6,7].

Corporate microlearning statistics show (figure 1) 58% of respondents said they would spend more time learning if content was presented in shorter, smaller chunks. 95% of eLearning trainers prefer microlearning to day-long seminars simply because the learners enjoy it more. 65% of employees are overwhelmed by the amount of information presented in a traditional training course. Microlearning can reduce development costs by 50% and even increase development speed by 300%. Using online learning tools can be challenging, but 58% are more likely to use them if they are presented using microlearning strategies, such as multiple short modules [8].

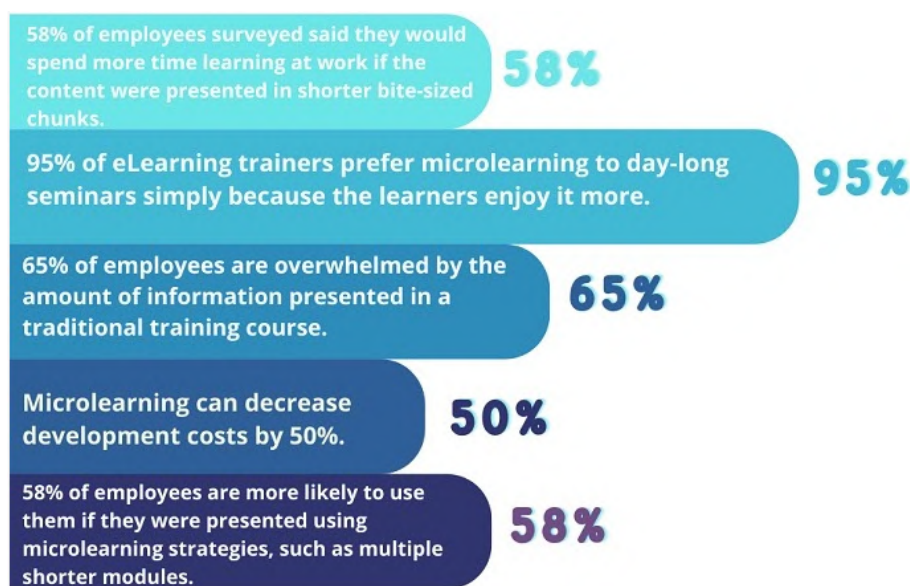


Figure 1. Corporate microlearning stats.

In fact, microlearning has been reported to improve learning transfer by 17% compared to traditional learning methods. In addition, it generates 50% more engagement, while reducing development costs by 50% and increasing development speed by 300% (figure 2) [9].

Video-based learning is better than text when it comes to engagement. Research shows that the human brain can process visuals faster than written text. Since videos combine sound, text, and movement, the audience seems instantly connected to them [10].

2. Theoretical background

Microlearning involves a more targeted approach to learning design in which unnecessarily redundant information is filtered out. This is to reduce cognitive load and the cluttering of



Figure 2. Advantages of microlearning compared to traditional learning.

working-memory with less relevant and extraneous information. By focusing only on small targeted “chunks” of vital information, absorption and retention becomes easier, thus making deep comprehension and application of knowledge more attainable [11]. Microlearning meets the learning attributes of the “new millennium learners” [12], for example, short attention span, needs for specific and in-time learning, and preference for instant feedback [13].

Microlearning seeks to address cognitive overload as a major barrier facing many learners today [14], by reducing information volume and making learning materials more attractive and engaging for students [15], [16]. Teachers can make microvideos by collecting detailed problem solving processes or ideas for typical problems such as difficult, key and error-prone problems. This way can create conditions for studying after class. In the microclass, you can also analyze and solve the problem from different angles and draw inferences about the problems [17]. Videos can be employed to teach other subjects through a foreign language also to low-level learners. It is important to analyze the learners’ needs, level of competence and background knowledge, in order to help them to develop listening and understanding strategies [18].

In our study, we will use a common approach to define microlearning – an educational strategy that focuses on learning new information in small chunks. This approach to learning breaks down topics into short, self-contained learning units that the learner can view as many times as necessary, whenever and wherever they want. Because microlearning can be implemented in a variety of ways, for example, short learning units within a discipline, short learning units in modular learning, short learning objects in corporate training, etc., it is important to understand how microlearning can be implemented in a variety of ways. In the present study, microlearning technology was applied within the discipline and involved the study of short learning units in video format, which allow students to develop specific knowledge and skills on certain topics or their logically complete parts, and to build an individual learning path using these short learning units.

Given that the format of the educational unit is a short video, it is necessary to study the parameters of the impact of using video content in e-courses when applying microlearning technology. Therefore, the purpose of this article is to study the impact of factors of video-oriented e-courses and microlearning technology on learning effectiveness. In order to assess this impact, the author developed a microlearning procedure and a system of quality factors for video-based microlearning technology and put forward the following hypotheses:

1. The developed procedure for microlearning based on video-oriented e-courses is effective and leads to an increase in the quality and satisfaction with the learning process.
2. The identified input factors, which allow to assess the quality of an e-course for microlearning, significantly influence the output factors, such as the results achieved by

the student, the evaluation of microlearning technology based on video content by teachers and students.

3. Methodology of research

The pedagogical experiment was carried out within the framework of the DAAD project “Support of the Digitalisation of Ukrainian Agricultural Universities, Line 2” (Project ID: 57649162) in cooperation with the National University of Life and Environmental Sciences of Ukraine (Ukraine) and the University of Applied Sciences Weihenstephan-Trisdorf (Germany).

The study uses the SBM-DEA model to conduct an empirical study with the participation of students of the National University of Life and Environmental Sciences of Ukraine (NULES) to assess the organization of microlearning technology based on video content, as the study aims to identify factors that affect the quality of the educational process.

In the last two decades, there have been remarkable advances in both Data envelopment analysis (DEA) methodologies and practical applications in many different fields (education, banking and finance, sustainability, arts and humanities, hospitals and healthcare, industrial sectors, agriculture, transportation, etc. [19]. There are many studies using the DEA model to evaluate the effectiveness of educational institutions and the organization of the educational process [20, 21], in particular, assessing the quality of project-based learning [22].

DEA model does not consider relaxation or congestion of input and output variables, but neglecting these factors may lead to issues in efficiency assessment, resulting in inaccurate assessment. Tone [23] proposed a measure based on relaxation variables for integrated SBM-DEA, which fully considers both the input and output relaxation variables. The SBM-DEA model is represented by formula (1)

$$\rho^* = \min \frac{1 - \frac{1}{m} \sum_{i=1}^m \frac{s_i^-}{x_{i0}}}{1 + \frac{1}{s_1 + s_2} \left(\sum_{r=1}^{s_1} \frac{s_r^g}{y_{r0}^g} + \sum_{r=1}^{s_2} \frac{s_r^b}{y_{r0}^b} \right)}. \tag{1}$$

SBM-DEA model can also adjust input and output variables through relaxation to improve efficiency. The adjustment mode of variables is represented by formula (2-5).

$$x_0 = X\lambda + s^- \tag{2}$$

$$y_0^g = Y^g\lambda - s^g \tag{3}$$

$$y_0^b = Y^b\lambda + s^b \tag{4}$$

$$s^- \geq 0, s^g \geq 0, s^b \geq 0, \lambda \geq 0 \tag{5}$$

When the result is $\rho^* = 1$, and all slack variables are 0, it represents that decision unit is effective. When $\rho^* < 1$, it represents that decision unit is non-effective. It can then adjust the original input to improve efficiency through slack variables. Adjustment form of corresponding variables is represented by formula (6-8).

$$x_0 \leftarrow x_0 - s^- \tag{6}$$

$$y_0^g \leftarrow y_0^g - s^g \tag{7}$$

$$y_0^b \leftarrow y_0^b - s^b \tag{8}$$

This study was conducted at NULES of Ukraine among teachers with experience in organising the educational process using microlearning technology and first-year students of the Knowledge Field 05 Social and Behavioural Sciences, Specialisation 051 Economics, and focused on determining the influence of factors on the quality of microlearning technology based on video content. Descriptive statistics and regression analysis were used to evaluate the results.

4. Findings

An e-course based on video content has been developed to organize the student's educational process using microlearning technology using a process approach [24]. This course includes tools for creating an individual learning path for a student based on previous experience, surveys before and after each microlearning element. When creating an e-course, it is difficult to differentiate learning material for different categories of students, namely by their level of preparation, motivation, learning styles, etc. It is therefore necessary to develop multi-level learning units. The study did not take into account the student's learning style, but only his or her previous experience in forming an individual trajectory. The adaptability of the learning content to the student's needs is one of the tasks to be solved when creating an e-course and forms the basis of the student's learning experience. The questionnaires used as input, intermediate and final control elements help to create an individual learning trajectory and the basis of the student's learning experience. The process of microlearning with the construction of such a trajectory is shown in figure 3.

At the beginning of the course, students take an entrance test, which leads to an individual learning plan and provides a transition to lessons with the presentation of educational material in the form of video content. In accordance with the individual learning plan, students are taught using the selected resources in a specific sequence and are subject to intermediate testing of the knowledge acquired. Analysis of the students' responses allows us to identify unformed competences, adjust the learning trajectory and return the students for additional study of the e-course material. Upon successful completion of the interim check, students are given access to the final test. The analysis of the answers given by the students in all the tests allows us to build up a database of the students' learning experiences, on the basis of which the teacher can adapt and update the e-course content.

The training elements of the e-course are presented in the form of an interactive video resource of up to 5 minutes in length. The interactivity of such video training material is ensured by short questions on the understanding and application of the material covered. Based on the answers given, the learner either continues learning or returns to review the material.

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4.1. A system of quality factors for video-based microlearning technology

In modern education, the quality of student learning using microlearning technology cannot be understood as the result of teaching and learning of students. The teacher should focus on achieving maximum learning efficiency for students, taking into account various elements of the learning content. Thus, the study of microlearning quality should not only include the assessment of students' learning achievements, but also the comparison and analysis of the maximum quality and efficiency achieved between the learning inputs and learning outcomes of each student. In this study, the results of microlearning are measured in terms of inputs and outputs. Based on research [20] and our own experience, we have developed a system of factors for evaluating the effectiveness of video-based microlearning.

The entry **factors include:**

- X1: Structure of the e-course (clarity of the course structure; correspondence with the educational programmer; content; availability of a syllabus and a short course summary);
- X2: Video resources (quality of the presentation of educational material in video format; short duration: from 5 to 15 minutes);

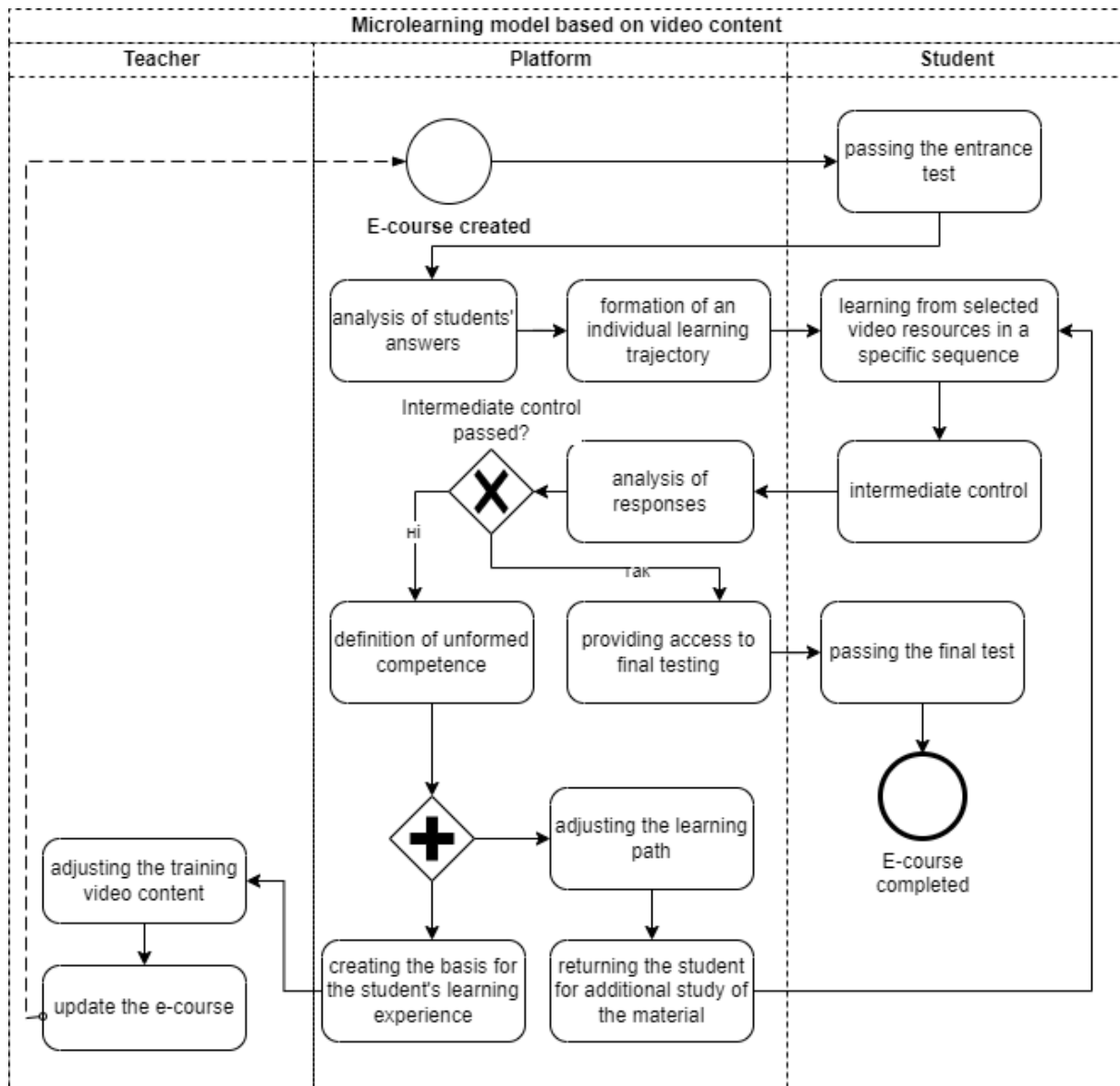


Figure 3. Microlearning procedure based on video content.

- X3: Tasks (correspond to the competences according to the syllabus; multi-level tasks; possibility to assess the input knowledge; availability of a valid intermediate check; availability of a final test);
- X4: Understanding of microlearning technology (knowledge of modern e-learning technologies; availability of help on learning tools and resources; availability of recommendations and instructions on the process; learning using an e-course);
- X5: Students' experience of learning with microlearning technology (implementation of microlearning through an accessible learning environment of the educational institution; availability of e-courses on different topics of the discipline);
- X6: Creation of an individual learning path (available tools for creation of an individual learning path; correctness of tasks for determination of individual needs for learning resources);
- X7: Adaptability of e-course content (cross-platform: access from different devices and operating

systems).

Exit factors:

- Y1: learning outcomes (average (cumulative) score for tests and practical and independent work; availability of review of results);
- Y2: course evaluation by students (students’ evaluation (opinion) of the experimental e-course);
- Y3: evaluation of the course by experts (teachers) (teachers’ evaluation (opinion) of the experimental e-course).

The experimental study involved 8 teachers from the Faculty of Computer Science and 31 first-year students in the field of knowledge 05 Social and Behavioural Sciences, specialisation 051 Economics as part of the discipline Information Systems and Technologies in Economics. In the first semester of 2023-2024, the students studied the module Types and sources of economic data using microlearning technology based on video content. Collecting data from experts on video-based microlearning technology by distributing a questionnaire in an e-course based on the Moodle platform. The experts assessed the quality of the microlearning technology based on the input and output factors identified in table 1. The results of the survey reflect the assessment of the input and output factors of microlearning quality based on the results of the study of this e-course. The questionnaire used a classic five-point Likert scale. Descriptive statistics of the results are shown in table 1.

Table 1. Descriptive statistical results.

Factor	Mean ± Standard deviation	Variance	Standard error	Kurtosis	Skewness	Coefficient of variation
X1	3.79 ± 1.38	1.90	0.22	-0.827	-0.751	50.18%
X2	3.87 ± 1.32	1.75	0.21	-0.787	-0.762	45.10%
X3	4.08 ± 1.13	1.28	0.18	-0.058	-0.959	31.48%
X4	4.21 ± 1.17	1.38	0.19	1.537	-1.553	32.77%
X5	3.85 ± 1.20	1.45	0.19	-0.798	-0.643	37.68%
X6	4.13 ± 1.17	1.38	0.19	-0.001	-1.084	33.38%
X7	3.87 ± 1.34	1.80	0.21	-0.026	-1.065	46.46%
Y1	3.85 ± 1.33	1.77	0.21	-0.093	-0.980	45.89%
Y2	3.82 ± 1.17	1.36	0.19	-0.609	-0.679	35.64%
Y3	3.82 ± 1.37	1.89	0.22	-0.724	-0.814	49.42%

The analysis of table 1 shows that there are no outliers in the current data set, indicating that the results of this survey are satisfactory. From the evaluation data, we can conclude that the experts have a good understanding of the factors associated with video-based microlearning technology.

In this study, the output-oriented SBM-DEA model was applied to assess the relative quality of student learning in a video-based microlearning technology. The SBM-DEA model, unlike the radial DEA models, works directly with slacks (excess input and shortfalls in output) and abandons the hypothesis of proportional changes in variables.

Table 2 shows the results of the expert survey in the form of a matrix, which indicates the assessment of input and output factors. Based on the assessment data, the efficiency coefficient of this learning technology was determined, which allows us to analyze the impact of input factors on the results obtained.

Table 2. Matrix of expert survey results.

Student number	Efficiency value	X1	X2	X3	X4	X5	X6	X7	Y1	Y2	Y3
1	0.85209	5	5	5	5	5	5	5	5	5	5
2	0.85209	5	5	5	5	5	5	5	5	5	5
3	1	2	5	5	5	5	5	5	5	5	5
4	0.55059	5	5	5	5	4	5	5	5	2	4
...
37	1	4	5	4	5	3	3	4	5	4	3
38	0.55317	5	3	5	5	3	3	4	2	2	3
39	1	5	5	5	4	3	4	1	4	4	4

The results of the DEA model show that out of the total number of respondents, the effectiveness of this learning technology was rated by 29 experts, which is 75% of the respondents and indicates the quality of this video-based microlearning technology.

In order to assess the impact of the input factors on the learning outcomes, a regression analysis was carried out figure 4.

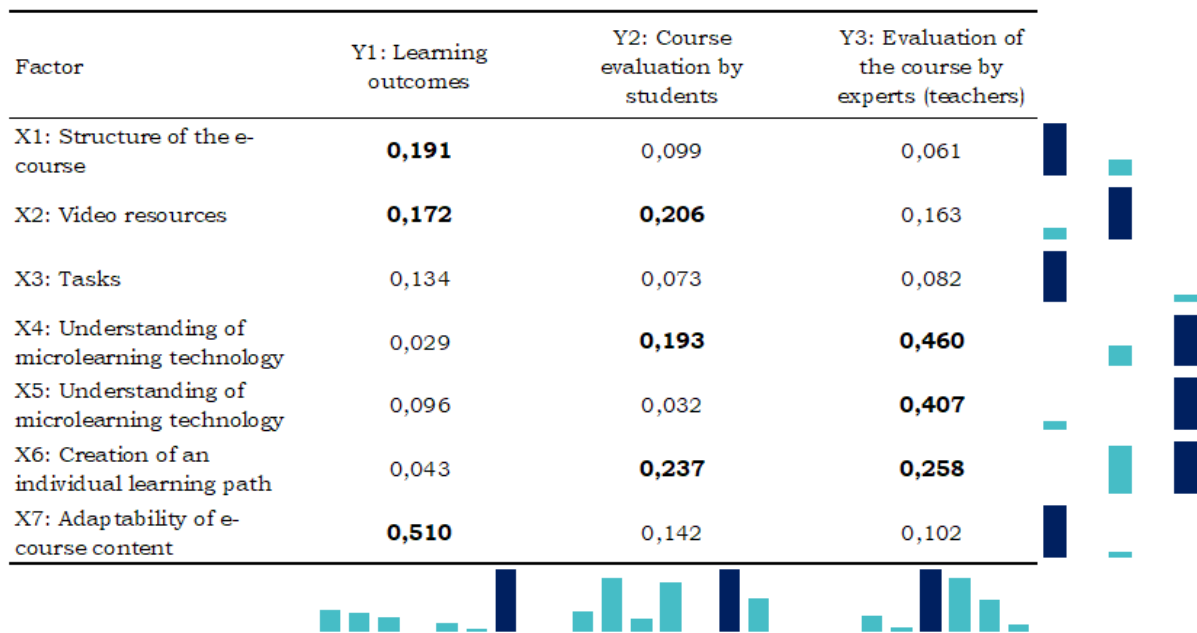


Figure 4. Regression analysis results.

The regression analysis shows that microlearning inputs have a significant impact on learning outcomes. The overall coefficient of determination is 0.72, which means that 72% of the variation in learning outcomes can be explained by the input factors. The learning outcomes (Y1) are particularly influenced by the adaptability of the e-course content (X7), the structure of the e-course (X1) and the video resources (X2). The formation of an individual trajectory (X6), video resources (X2) and understanding of microlearning technology (X4) have a significant impact on students' evaluation of the course (Y2). The evaluation of the course by experts (Y3) is largely

dependent on the understanding of microlearning technology (X4), the students' experience of learning with microlearning technology (X5) and the formation of an individual trajectory (X6).

Since microlearning is at the stage of experimental implementation in NULES of Ukraine, it involves a constant exchange of teaching experience, gradual improvement of conditions for organising the educational process using this technology. As teachers gain more teaching experience and other factors gradually improve over time, the quality of teaching tends to increase with each academic year, which will improve the quality of students' learning in modern conditions.

5. Conclusions

Microlearning technology fully meets the requirements of modern university education, which advocates the use of innovative approaches, methods and technologies of teaching. The main objective is to assess the quality of microlearning technology based on students' video content using the SBM-DEA model. This study has led to the following conclusions: firstly, only 75% of the experts in the evaluation identified this learning technology as effective, which indicates that although they have used e-courses in the educational process, the quality of learning has not improved in their opinion. Therefore, it is necessary to pay more attention to the influence of other factors of the educational process, such as the learning environment, the availability of different tools integrated in the educational environment of the educational institution, satisfaction and motivation of learning. Secondly, the study finds that the lack of tasks and the availability of video resources are the main factors influencing the low quality of student learning. It is suggested that further research be carried out to determine the components of teacher competence in creating e-courses and organizing microlearning in different disciplines and, consequently, educational programmes, how the introduction of microtechnology affects students' motivation and satisfaction as well as their academic performance. Since the quality of the video resource has a significant impact on learning outcomes, it is necessary to further assess which parameters of the video resource most influence learning outcomes in order to develop recommendations for video content creators. In addition, it is considered promising to study the current market of e-course platforms, on the basis of which it is possible to implement the task of building an individual educational trajectory and creating a database of students' learning experiences. To study the functionality of such platforms and to determine other parameters of their selection for the implementation of microlearning technology based on video content.

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The formation of visual thinking of students in technical universities in the context of higher mathematics education

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Abstract. The visualisation of teaching higher mathematics as a development of information and communication technologies determines the transition of the educational process to a new level of its development. As a result, it should focus on the visual orientation and modern practice of its use. The question arises as to the formation of students' visual thinking as a necessary component of the training of a modern specialist. In this context, a study has been conducted on the problem of using visual information and its visual perception in teaching higher mathematics on the example of individual sections, as well as techniques of justification based on visual information. The examples offered in the article form the skills of working with graphic information. Developing visual thinking, they fix attention during the learning process, implicitly and indirectly contributing to the conversion of mental content into a visual image, ensuring the formation of a more complete picture of an image or concept. The article analyses the results of using visualisation in the educational process of students of technical universities. The influence of visualisation on the level of students' knowledge is analysed. In particular, the ability of a certain contingent of students to perceive and use visual images, their ability to think and express thoughts in images, perceive the content of logic, emotions contained in visual information, as well as the ability to operate with visual images in communication, establish cause and effect relationships and relations between concepts, as well as memorise and reproduce ideas about objects is noted.

1. Introduction

In the context of the increasing amount of information and the active “immersion” of youth in the consumption of visual media, the issues of visualizing the thinking of students at technical universities are becoming increasingly relevant [1–3]. Often, the effectiveness of learning mathematics for students is limited precisely by the difficulty of perceiving mathematical abstractions [4, 5]. The need for visualization of educational information is determined by the peculiarities of modern students' thinking, namely: the ability to quickly switch attention and to process information quickly; a preference for perceiving graphical information, and at the same time, an unadaptability to the perception of linear and homogeneous information, especially large book texts [6]. According to the authors, the main obstacle to a deep understanding of mathematics by students of technical universities is the insufficient development of abstract and logical thinking. This deficiency can be somewhat remedied by forming visualizing some



basic concepts in mathematics. Overcoming this barrier in some topics will undoubtedly make it easier to perceive the material of other sections, where visualization is either impossible or limited. Free operation of visual objects is an important component of the professional training of future specialists in technical fields and their professional competence. The problems of effective methods of modern presentation of educational material, based on the psychological principles of cognitive visualization, are discussed by Babych and Semenikhina O. [7], Bezuglyi [8], Drushlyak [9], Reznik [10], Bilousova and Zhytienova [11], Gurzhii et al. [12], Gritchenko et al. [13], Zhytienova [14], Lipchevska [15], Rudenko [16], Nind and Lewthwaite [17].

The aim of the article is to theoretically substantiate and practically test the effective methods of modern presentation of educational material in higher mathematics, based on the principles of cognitive visualization.

The hypothesis of the research is as follows: formation of visual thinking as a means of systematizing concepts in the course of higher mathematics helps to improve understanding of mathematical concepts.

2. Materials and methods

To achieve the goal, the following scientific tasks were defined:

1. To analyze the current trends in the field of higher mathematics teaching and the use of visualization in the educational process.
2. To develop a theoretical concept that explains how visualization can influence the systematization of mathematical concepts, concepts understanding and student motivation.
3. To develop educational materials that use techniques and principles of cognitive visualization for presenting higher mathematics material.
4. To conduct a practical appraisal of the developed educational materials in an academic environment to collect data on their effectiveness and interaction with students.
5. To perform an analysis and evaluation of the obtained results, determining how successful and effective the developed techniques and educational materials were to understand the concepts of the higher mathematics course.

The following methods were used to solve the tasks set in the work: critical analysis and synthesis, induction, logical generalization, comparison, graphical and tabular analysis, etc.

3. Theoretical background

At the stage of reforming the education system, adapting to the demands of the society and the development of science and searching for new teaching methods, one of the issues that requires review and clarification is the use of visual aids as one of the main principles of didactics [18]. According to this principle, the perception of an object is possible visually, audially, kinetically and verbally. In this situation, the main task of educational activity is to maximally include visual process tools or visualistics in the educational process.

In pedagogy visuality is understood as one of the main principles of didactics, according to which teaching is based on concrete images that are directly perceived by the learners. The concept of visualization varies among authors. Some believe that visualization is the presentation of numerical and textual information in the form of graphs, diagrams, structural schemes, etc. Others view visualization as the process of presenting data through depiction [7, 8, 11].

The definitions encountered in scientific publications regarding the term “visualization” differ in their generic concept. Some authors perceive visualization as a ready presentation of numerical and textual information in the form of graphs, diagrams, structural schemes, tables, maps, etc. Others believe that visualization is the process of representing data through images for the purpose of maximizing their comprehensibility; giving a visible form to an object, subject

or process. The terms “visibility” and “visualization” are typically equated. However, a detailed analysis of scientific and pedagogical research dedicated to the theoretical foundations of visualizing educational material, types, and means of visibility, as well as the theoretical foundations of visual learning support, visual thinking, practical issues of creating visualization tools, etc., shows that these concepts differ from each other. Among the types of visibility, scientists highlight visual clarity so the visualization of educational material can be included in the generic concept of “visibility” as a type. The interpretation of the term “visualization” implies the process of creating a visual image whereas the term “visibility” is associated with an already formed image of the educational object. This allows us to assert that the concept of visualization of educational material goes beyond the scope defined by the term “visibility” [7].

In our view, visualization is a specific category of didactics including the mechanisms of imagination, establishing and consolidating associative links between visual images and the properties of fundamental concepts, and the process of visualizing educational material that involves not only reproducing a visual image, but also the process of its creation as a means of reflecting the facts of reality.

The assertion of visuality as one of the most important factors of modernity is a logical result of the “information boom”. It has “overloaded” people with information, the processing of which exceeds their cognitive, mental, temporal and social resources. As a result, the way of perceiving as well as the way of analyzing reality are changing.

Visual types of communication transform education on a global scale where there is a transition from printed means of information relay to visual forms. This circumstance naturally entails an expansion of the influence of visualization on the educational process and education in general.

Modern forms of visualization of educational material include: reference notes, frames, logical-symbolic models, block diagrams, graph schemes, dynamic models, mental maps, interactive timelines, internet memes, tag clouds.

Visual images are not just an illustration of the author’s thoughts, but the final expression of thinking itself. Unlike the usual use of visual aids, the work of visual thinking is an activity of the mind in a special environment which makes it possible to transition from one presentation of information to another, to comprehend the connections and relationships between its objects. In that we see the mechanism of activating thinking through visibility. As stated in the work [8], the main purpose of visualization in teaching is to support logical operations at all stages of educational activity and this is the most important issue when performing analytical actions (analysis, synthesis, comparison, search for connections and relationships, systematization, conclusion, etc.).

Among the functions of visualization are also the development among the students the skills to establish cause-and-effect relationships and relations between concepts, as well as skills in memorizing and reproducing images of objects, developing imagination, concentrating attention, etc.

The content of education is the core that connects all levels of the education system, defining their sequence and continuity. In shaping the content, it is important to establish a balance between the fundamentality and professional orientation of training, realizing the principle of visualization.

The main principles that guided us during the development of the content of educational information visualization are defined as follows:

- the development of visualization of educational information in a technical university must be based on a model that includes the goals of using visual means as a component;
- the combination of the visualization means with the ways of organizing students’ independent educational and cognitive activities;

- the methodological approach to organizing the teaching process requires determining the optimal structure of information based on didactic principles;
- the enlargement and visualization of educational information can be realized by various methods and corresponding symbolic models of knowledge representation;
- structuring the content of educational information is based on identified elements of knowledge;
- the application of visual educational information in the teaching process implies the systematic use of visual models of a certain type or their combination in the educational process.

Accompanying the study of mathematical concepts through prior analysis of their visual images (where possible) gives a new quality to higher mathematics classes. Visual thinking is an element of figurative thinking. Where possible, logical thinking should be developed with the inclusion of figurative thinking. In this case, mathematical abstractions find concrete embodiment and the assimilation of mathematical concepts occurs more easily, quickly and becomes more solid. Visual images directly affect the senses, their perception and understanding are more accessible than the perception of analytical information. Visual interpretation of many mathematical statements helps make them more transparent for assimilation.

Scientists propose various ways to solve the problem of forming a system of concepts – writing a genealogy of the concept, classification of concepts. For concepts of mathematical analysis, reliance on graphical, visual representations is relevant. Therefore, it is natural to assume that this approach will work in forming a system of concepts. What is the specificity of using visualization of concepts of mathematical analysis in forming their system?

First of all it is necessary to consider visual (graphical) representations of concepts and only then to move on to its analytical representation. Such an approach will allow for a linear study of mathematical analysis, and for forming a system of concepts, it is necessary to include tasks in the learning process that carry the sense of expanding the application of the theory of one section of analysis to other sections, i.e., transferring the concept from one section to another based on their visual images.

Thus, the visualization of concepts and tasks of applying the concepts of mathematical analysis of one section in the tasks of another section are identified as necessary conditions for systematizing the concepts of mathematical analysis. The high degree of abstraction in presenting information about concepts and their properties in the process of teaching mathematics to students of technical universities necessitates such an organization of mathematics teaching where the representations that arise in the minds of students reflect the main and essential aspects of mathematical objects and laws, in particular through the visual presentation of mathematical content.

It is necessary to achieve that the recall of a concept is primarily associated with the corresponding visual factor. The transition from a visual representation to a formal definition is the next step in forming a stable representation of a particular concept. Since this representation in such an approach is based on a visual image, students should more consciously, confidently, and with fewer errors define the various properties of the functions being studied, apply the learned concepts to solving tasks.

From the point of view of cognitive psychology, the visual context, firstly, gives students an external reference that reinforces and supports their expectations, namely, the substantive representation, prediction of performing corresponding actions; and secondly, forms an essential stimulus for perceiving new information. A varied form of stimulus, presented at a high frequency and reinforced by a visual context, allows not only to quickly classify or recognize perceived information, but also to effectively assimilate it at an actively operative level, i.e., to translate it from the algorithmic sphere of activity into the productive one.

As for the lecture-visualization, it can be most effectively used during the consideration of generalizing and abstract topics that are difficult to perceive in traditional lectures, as well as in initial lectures with the aim of increasing students' interest in the content of the lecture. The possibilities of lecture-visualization are offered to be used at the stage of starting a new section, for example, vector analysis (field theory).

In figure 1, a vector field, vector lines, an element of a field flow tube, a vector gradient, the physical formation of circulation and the rotor of a vector field are depicted. Such a visual acquaintance with mathematical concepts, the visual perception of their properties, connections and relationships between them in lectures and practical classes allows to quickly and visually unfold before students individual fragments of the theory, to form and spread a generalized algorithm of operations, to apply the acquired knowledge and skills to the cognition of the content of other fields of knowledge.

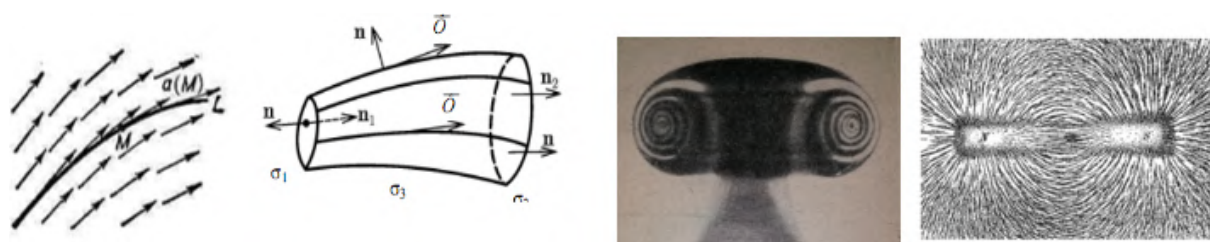


Figure 1. The visualization of basic concepts of the field theory.

However, lecture-visualization also has its drawbacks, particularly the rapid pace of information delivery can create difficulties during the note-taking of educational material. For better absorption of new knowledge it is advisable for students to be provided with educational material for review or the main text of the lecture for preliminary familiarization and a set of visual aids without text and connections, so that during the lecture students only need to take notes on explanations and not have to draw diagrams and figures.

In this case, it is appropriate to adhere to didactic requirements:

- not to overload the lecture with visual objects as this reduces the educational and cognitive activity of students;
- a visual object should not contain superfluous information to avoid the emergence of side analogies and associations.

Unlike the traditional use of visual aids, the work of thinking during the perception of a visual object is an activity of the mind in a special environment which makes it possible to transition from one form of information presentation to another, to understand the connections and relationships between objects.

Visualization plays an important role in systematizing and understanding the concepts of higher mathematics. It can help students transform abstract mathematical concepts into concrete visual images, easing their perception and memorization. Here are some ways to use visualization for systematizing concepts in higher mathematics:

Graphs and visual representations of functions:

- The construction of graphs of mathematical functions, the analysis of their shape and properties.
- Studying the changes in graphs with changes in the parameters of functions.

Vector algebra and geometry: Work with vectors, matrices, and operations on them, which can be visualized using vectors in space.

- Applying geometric concepts to solving problems using visual models.

Differential and integral equations:

- Studying the change in functions using concepts of derivatives and integrals through their graphs.
- Applying visual representations to solve problems in kinetics, motion.

Trigonometry and geometric figures:

- Studying trigonometric functions and their graphs to understand the relationship between triangles and angles.
- Applying geometric properties to analyze functions and their graphs.

Complex numbers and geometry on the complex plane:

- Studying complex numbers and their representation on the complex plane.
- Using complex numbers for the visual representation of geometric transformations.

Three-dimensional models:

- Using three-dimensional models to illustrate vectors, spatial relationships, and geometric constructions, visualizing curves in three-dimensional space.

Let's consider an example where, thanks to visualization, the solution of a Cauchy problem (1) allows the student to perform elements of qualitative analysis of integral curves.

$$y' + y\cos(x) = \exp(-\sin(x)), \quad y(0) = 2. \quad (1)$$

A student conducts an analysis of the corresponding process based on the construction of a fragment of the relevant integral curve (figure 2) and attempts to predict what the other integral curves will be like. It's important to analyze the content of the general and particular solutions. The content of the general solution (usually, within the set of constructed graphs) allows one to determine the features of the dynamics of the process and to identify its behavior near certain points. The analysis of such situations enables students to realize the significance of mathematical modeling. For example, the graph of a particular solution (figure 2) indicates the presence of a significant number of extrema, and at the same time, the graphs of the general solution (figure 3) characterize the process differently near certain points (the max point changes to a min point). This visual approach to learning mathematics forms the ability to interpret information presented in a mathematical way, to use mathematics accurately for conveying information and solving problems [19].

Visual representation of mathematical concepts, visual perception of their properties, connections and relationships between them allow to quickly and visually unfold individual fragments of the theory before students focusing attention on the key moments of the problem-solving process. Consider this in the example of a qualitative description of dynamic systems. It usually comes down to constructing phase portraits. For visualizing the phase space, both general-purpose programs like Mathematica, MathCAD and specialized programs are used. It's necessary to build a phase portrait of the system of differential equations and ensure that the non-closed integral curves on the phase plane correspond to the non-periodic solution of the system. For this purpose, construct a three-dimensional model of the system (2).

$$\begin{cases} \frac{dx}{dt} = a_{11}x + a_{12}y; \\ \frac{dy}{dt} = a_{21}x + a_{22}y. \end{cases} \quad (2)$$

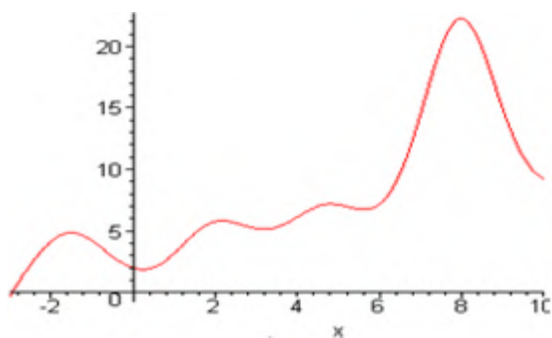


Figure 2. The graph of the particular solution, $y = (x + 2) \cdot e^{-\sin x}$.

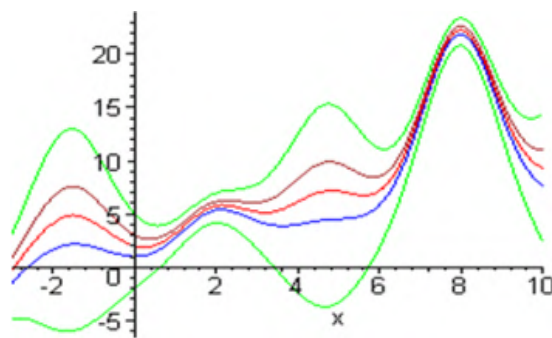


Figure 3. The graph of the elements of the general solution, $y = (x + C) \cdot e^{-\sin x}$.

In figure 4, the phase portrait of the system is presented, and in figure 5, a three-dimensional model of the system is shown (for specific values of coefficients and initial conditions). Figure 4 depicts the orthogonal projection of the system's phase portrait onto the XY coordinate plane (similarly, orthogonal projections onto the XZ and YZ coordinate planes can also be considered).

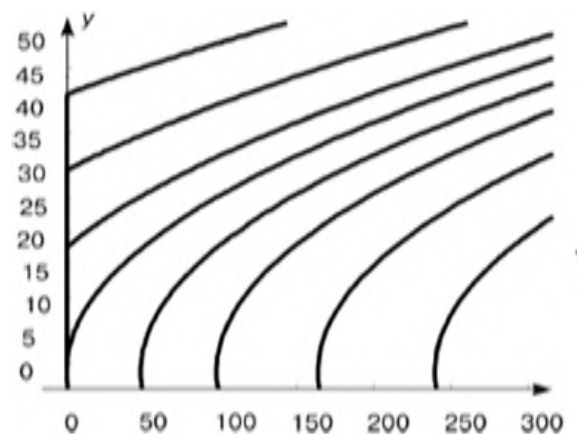


Figure 4. The phase portrait of the system.

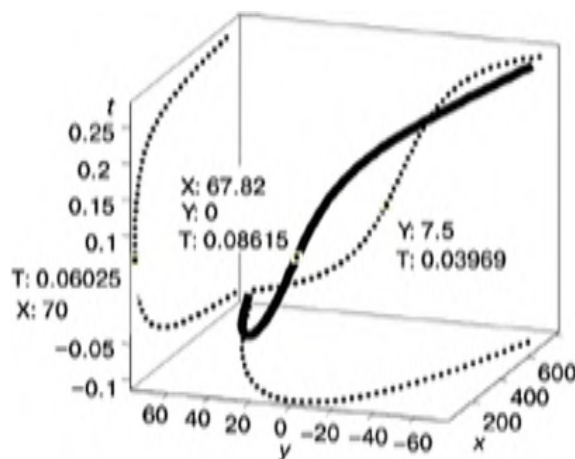


Figure 5. A three-dimensional model of the of differential equations system of the solution.

The visualization mentioned indicates that the solution of the system is not periodic (as shown in figure 5), hence the integral curves on the phase plane are not closed.

This is a crucial insight in the study of nonlinear dynamic systems. Apart from constructing and analyzing the phase space using various numerical algorithms, computer visualization enables students to comprehend important concepts of synergetics, such as limit cycles and strange attractors.

Experience with first-year students shows that they do not always clearly understand what it means to find the root of an equation with a given accuracy. By definition, x_i is an approximation of the root of the equation $f(x) = 0$ with accuracy ϵ if the condition $|x_i - \xi| < \epsilon$ is met, where ξ is the exact root of the equation.

The problem arises because the exact root ξ is unknown (and mostly will not be found), so the actual difference $|x_i - \xi| < \epsilon$ cannot be calculated. Students who are comfortable with numbers often ask questions like “What should be compared?”, “When should the process of

finding the root be stopped?”, “Why are the conditions $|x_i - x_{i-1}| < \varepsilon$ or $|f(x_i)| < \varepsilon$ most often used to ensure the specified accuracy?”. The best way to address these issues is visually, by showing examples of intervals $[\xi, x_i]$, $[x_{i-1}, x_i]$, $|f(x_i)|$.

Visualization helps clarify confusing areas and, in addition, enables choosing the criterion for stopping the process depending on the behavior of the function $f(x)$ (for example, the condition $|f(x)| < \varepsilon$ is not suitable for rapidly growing functions).

The visualization of “machine epsilon” is particularly interesting for students. When constructing graphs, “machine epsilon” can be used to visualize small differences between numbers that, although very close, still differ due to the limited accuracy of floating-point numbers. It’s important for students to understand that this is crucial in areas where accuracy is key, such as numerical computations or signal processing. The impact of “machine epsilon” on graphical representation can arise, in particular, in cases involving interaction with graphs or data where the precision of numerical values matters. Here are a few situations where this may become noticeable:

- *Graphs of functions:* If the graph of a function has values very close to 1, then “machine epsilon” might cause the expression to be rounded to 1 when displayed on the graph. This can lead to underrepresentation or loss of some details in the visual representation (figure 6).
- *Comparison of values:* When comparing numbers on a graph (e.g., determining the points of intersection of curves), “machine epsilon” might cause values with minor differences from 1 to be perceived as equal, affecting the correctness of graph analysis.
- *Processing of graphical data:* In working with graphical data, such as images, “machine epsilon” can influence calculations or comparisons of pixel values, which can also affect image processing or graph analysis.

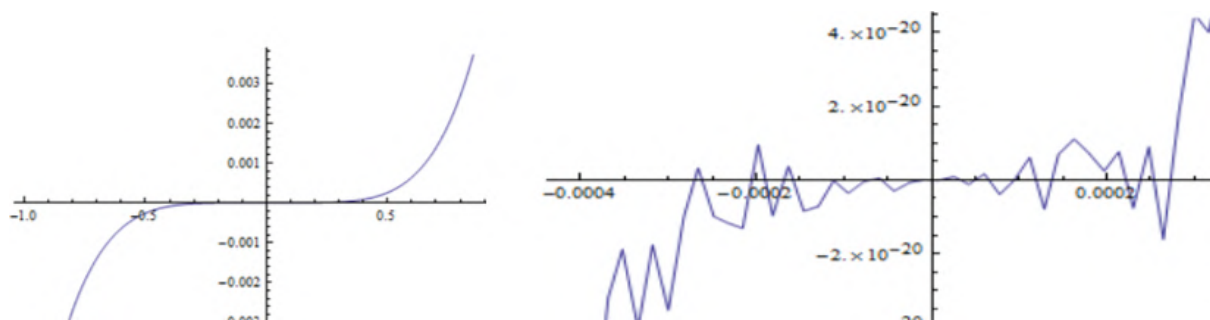


Figure 6. The structure of the graph connected with “machine epsilon”.

Thanks to appropriate visualizations, students not only hear such information but also understand that when developing very accurate algorithms or in tasks where high numerical precision is critical, attention should be paid to the impact of “machine epsilon”.

The process of perceiving, understanding, and memorizing knowledge quickly is based on visual cognitive images. Cognitive visualization has deep genetic forms and is used in various activities, of which the following are directly related to the sphere of higher mathematics education: aggregating significant didactic units of information (elements of knowledge) and their reproduction through various schematic-symbolic means; demonstrating theoretical formalized knowledge in a visual form necessary for easing perception; multidimensional visualization of problem areas in intellectual information technologies, such as the structural-logical scheme of studying a higher mathematics course.

According to the above mentioned methods of cognitive visualization, which are directly related to the field of higher mathematics education, the following levels of visualization can be identified in didactic means, based on the degree of adequacy to the objects:

- Reference signals, tables for aggregating information, the method of reference notes, workbooks, etc;
- Structural-logical schemes, graphs, and methods of schematizing knowledge;
- Modeling (logical-content models).

At each of these levels, key modeling principles are implemented: structuring information, linking elements of the structure, and aggregating information.

It should be noted that visualization of educational material reduces its verbal explanation, thereby aggregating information. For example, presenting material in the form of a presentation is a vivid example of such condensation.

Visualization of educational material at the first level allows its presentation as a guide for action in a form convenient for memorization and reproduction based on assimilated associations.

The effect of schematizing educational knowledge through structural-logical schemes (the second level) lies in the visual representation of the hierarchy of diverse elements of knowledge and concepts, indicating internal logical connections between them using directed lines that connect them. Structural-logical schemes help visualize, organize, summarize, visually build knowledge and concepts, freely navigate in the material, and correctly systematize it.

The third level of visualization (modeling) represents a new frontier in the theory and practice of didactic clarity, occurring at the level of designing new aesthetic, technological didactic means of the modeling type. The modeling form of knowledge representation is characterized by compactness and is a necessary form for performing, supporting assimilated information at all stages of activity – perception, processing, storage, reproduction, etc. It should be noted that there is a gradual transition from partially intuitive compilation of visual didactic means to their design using various compact elements of image models (conceptual, pictogram, sign-symbolic, etc.), as well as visually convenient methods of their logical organization.

The level of development of visual thinking can be assessed using various criteria that evaluate the ability of students to analyze, interpret, and use visual representations in the context of higher mathematics and engineering tasks. We offer the following criteria:

1. *Graphic skills:*

- Ability to create quality graphs of mathematical functions and analyze their shape and properties.
- Ability to use graphs to solve mathematical problems.

2. *Spatial thinking:*

- Ability to identify and understand spatial relationships, especially in the context of vectors, matrices, geometric objects.
- Use of visual representations to solve problems involving three-dimensional space.

3. *Working with computer programs:*

- Ability to effectively use computer-aided design (CAD) programs and other engineering tools.
- Application of visual capabilities of programs to solve engineering problems.

4. *Use of visual representations in analysis and problem solving:*

- Ability to use visual models to solve complex engineering problems.
- Study and analysis of visual data to solve mathematical tasks.

5. *Visual communication:*

- Ability to clearly and effectively present engineering ideas through visual means.
- Ability to prepare visual presentations and documentation.

These criteria were used to develop tasks and assessment tools that allow evaluating the level of development of visual thinking in students of technical specialties.

4. Results and discussion

In accordance with the set goals and hypotheses of the study, a pedagogical experiment was conducted in the first term with first-year students of specialty 121 – Software Engineering.

The purpose of the pedagogical experiment was to determine the effectiveness of modern methods of presenting educational material in higher mathematics, based on the psychological principles of cognitive visualization.

During the experiment, the hypothesis was tested: the use of innovative methods of presenting mathematical material using elements of visualization would contribute to the formation of visual thinking in students of technical universities, improving the process of assimilation and understanding of mathematical concepts.

In the initial stage of the experiment, 150 first-year students were tested using a preliminary written test to determine the initial level of development of visual thinking as far as the formation of mathematical concepts is concerned.

The majority of students, as shown by the testing, had a low level of development of visual thinking, as evidenced by the results presented in table 1.

Table 1. The results of the students’ testing for identifying the initial level of visual thinking formation as for the formation of mathematical concepts.

The initial level of visual thinking formation	low	medium	high
The amount of students (150 people)	102 (68%)	39 (26%)	9 (6%)

A high level of development of visual thinking and heuristic skills was mainly shown by students who were talented in mathematics and who once again confirmed their results.

Additionally, at the beginning of the study using the experimental methodology, students were divided into control (C) and experimental (E) groups. Based on the results of the initial control work at the beginning of the study, the level of mathematics preparation of the students in these groups was determined (residual school knowledge and skills in mathematics were tested).

To test the statistical significance of the difference between the samples of marks for residual school knowledge of mathematics of students in the experimental and control groups, the Pearson criterion χ^2 was used. The null hypothesis in this case was formulated as follows: there is no statistically significant difference between the two empirical distributions. It was shown that this difference is not statistically significant, meaning there is no difference in residual school knowledge of mathematics between groups E and C. The statistical data obtained as a result of the pedagogical experiment meet the conditions for applying the Pearson criterion χ^2 : the samples are random and independent; the sample size is more than 20; the sum of observations across all intervals equals the total number of observations.

To calculate χ^2 , the formula was used: $\chi_{emp}^2 = \frac{1}{n_1 \cdot n_2} \sum_{i=1}^n \left(\frac{n_1 Q_{2i} - n_2 Q_{1i}}{Q_{1i} + Q_{2i}} \right)^2$ where n_1 is the sum of all grades of the first sample, n_2 is the sum of all grades of the second sample, Q_{1i} , Q_{2i} is the number of students in the experimental (control) group belonging to category i ($i = 1, 2, 3, 4$) according to the state of the property being studied. In our case n_1 is the sum of all grades

of students in the experimental group, n_2 is the sum of all grades of students in the control group [20].

The number of degrees of freedom is found using the formula $v = (k - 1)(c - 1)$, where k is the number of samples being studied, c is the number of gradations in the samples being studied. If the inequality $\chi_{emp}^2 > \chi_{cr}^2$ is met, then the null hypothesis is rejected at the significance level α and the alternative hypothesis is accepted, but if $\chi_{emp}^2 < \chi_{cr}^2$, then the null hypothesis is accepted, i.e., there is no sufficient basis to consider the state of the property being studied different in both samples.

For example, let's describe the statistical processing of results of the E group (72 students) and the C group (78 students). The total number of grades received by the students is presented in table 2.

Table 2. Total grades of residual school knowledge in Mathematics.

Groups of initial research	Grades				Σ
	1-3	4-6	7-9	10-12	
Experimental	$Q_{11} = 15$	$Q_{12} = 42$	$Q_{13} = 12$	$Q_{14} = 3$	72
Control	$Q_{21} = 20$	$Q_{22} = 45$	$Q_{23} = 11$	$Q_{24} = 2$	78
Σ	$Q_{11} + Q_{21} = 35$	$Q_{12} + Q_{22} = 87$	$Q_{13} + Q_{23} = 23$	$Q_{14} + Q_{24} = 5$	150

As a result of the calculations based on table 2, we obtained: $\chi_{emp}^2 = 0.67$.

According to the table of critical values for the Pearson χ^2 criterion, we find that $\chi_{cr}^2 = 11.345$ ($\alpha \leq 0.01; v = 3$). We obtained that $\chi_{emp}^2 < \chi_{cr}^2$. Therefore, the null hypothesis is accepted. The difference in the total distribution of grades for residual school knowledge in mathematics in groups E and C is statistically not significant, therefore, there is no difference between the residual school knowledge in mathematics in the experimental and control groups.

The identification of the levels of formation of visual thinking in students was carried out using criteria (graphic skills, spatial thinking, work with computer programs, use of visual representations in analyzing and solving problems, visual communication) that allowed assessing the level of correctness and completeness of solving standard tasks and tasks using visualization.

The results of the experiment are presented in table 3.

Table 3. Total grades of residual school knowledge in Mathematics.

Groups	Number of students	Tasks			
		Standard task		Task with the use of visualization	
		Correct solution	Complete and correct solution	Correct solution	Complete and correct solution
Experimental	72	67	62	48	43
Control	78	65	56	30	23

Present the data of the table in the form of a diagram (figure 7).

Taking into account the obtained results, we will evaluate the probability of the E group's superiority compared to the C group in terms of correctness and completeness of task solutions, using the Wilcoxon-Mann-Whitney criterion.

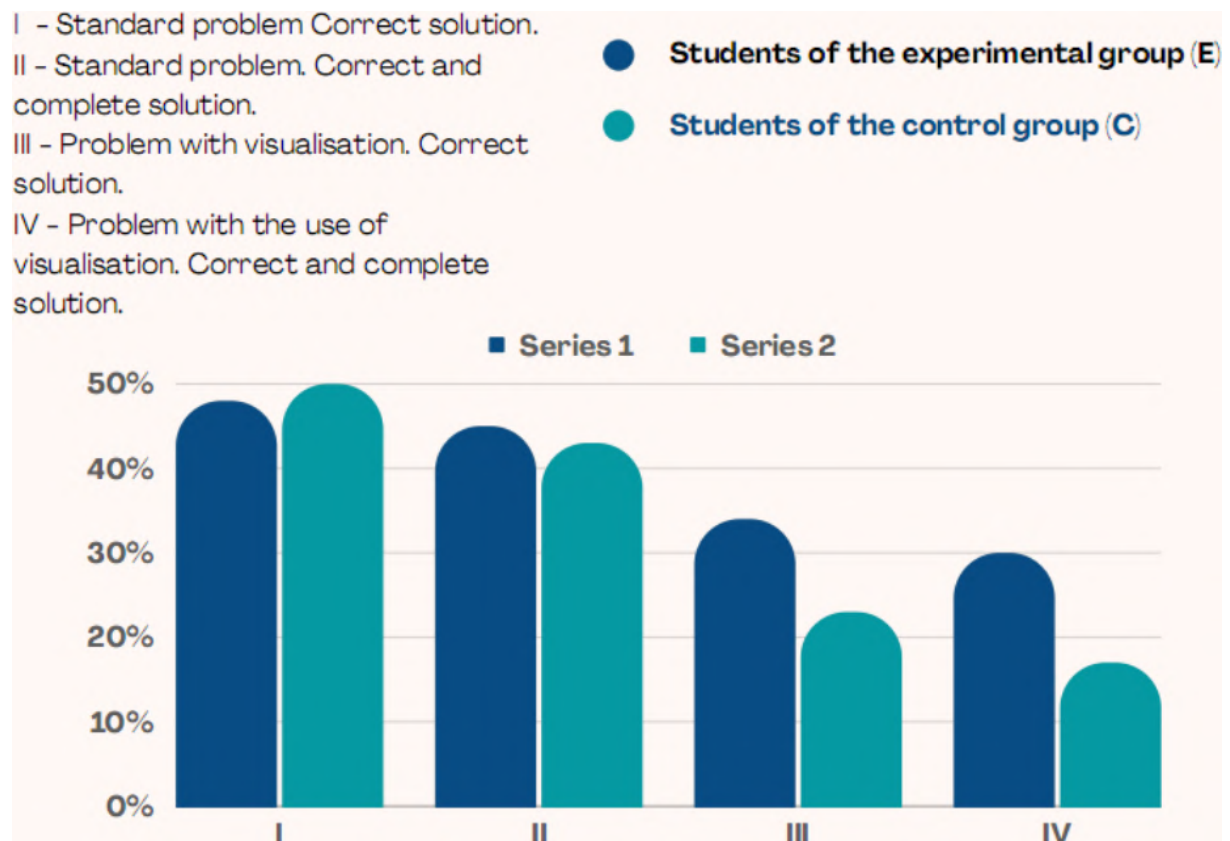


Figure 7. Experimental study of the formation of visual thinking.

The Wilcoxon-Mann-Whitney criterion is used in pedagogical research, as it allows testing several assumptions about the nature of distribution differences of a certain property in two populations (differences in medians, average values of both populations' distributions, as well as the presence of a tendency for objects of the first population to be on average larger or, conversely, smaller than members of the second population) based on ordinal measurements of the state of this property. Therefore, to test the statistical significance of the divergence between the samples of grades obtained by students in a control work consisting of standard tasks and tasks using visualization, and taking into account the results of evaluating the probability of the E group's advantage over the C group in terms of completeness and correctness of solving tasks, we used precisely this criterion [20].

The hypothesis being tested is $H_0: P(X < Y) = \frac{1}{2}$ at the significance level $\alpha = 0.01$ ($x_{\alpha/2} = 1.64$) with the alternative $P(X < Y) < \frac{1}{2}$. The correctness and completeness of the solution were assessed on a dichotomous scale. That is, the hypothesis H_0 assumes that the completeness and correctness of solving standard and problems using the visualization of the control work of the students of the experimental group (variable X), with the same probability equal to 0.5, is statistically more or less than the completeness and correctness of solving the problems by the students of the control group (variable Y), that is, students of both groups will solve problems at the same level. At the same time, the statistical data obtained as a result of conducting a pedagogical experiment meet the conditions for applying the Wilcoxon-Mann-Whitney criterion: the samples are random and independent, the members of each sample are also independent of each other; the sample size is more than 20; the property of objects under study is continuously distributed in both samples. According to the rule of using the criterion,

the members of the two samples are combined into one, which has a size of $N = n_1 + n_2$, are written in a row in ascending order and ranked, i.e., each member of the row is assigned a rank, which numerically equals the place number this member occupies in the row. If several consecutive members of the row have the same value, each is assigned the same rank, equal to the arithmetic mean of the place numbers these members occupy. To test hypotheses using the Wilcoxon-Mann-Whitney, first calculate the sum of ranks S : $S = \sum_{i=1}^n R(x_i)$, where $R(x_i)$ is the rang assigned to the i -th object of the sample, n_1, n_2 are the sample sizes, and n equals the smaller of the values n_1, n_2 . The value of the criterion statistic T is calculated using the formula (3):

$$T = S - \frac{n(n + 1)}{2}. \tag{3}$$

If at least one of the values n_1, n_2 is greater than 20, then the critical value of the T-statistic is calculated using the formula (4):

$$W_{\alpha/2} = \frac{n_1 n_2}{2} + x_{\alpha/2} \sqrt{\frac{n_1 n_2 (n_1 + n_2 + 1)}{12}}, \tag{4}$$

where $x_{\alpha/2}$ is the quantile of the normal distribution for $\alpha=0.01, x_{\alpha/2} = 1.64$.

The null hypothesis $H_0: P(X < Y) = \frac{1}{2}$ is rejected at the significance level α if one of the inequalities $T_{obs} < W_{\alpha/2}$ or $T_{obs} > n_1 n_2 - W_{\alpha/2}$ is true.

For an example of calculation, let's assess the correctness of solving a standard problem.

Let's compare the results of groups E and C. Out of 72 individuals in group E, 67 students succeeded in solving the problem. From 78 individuals in group C, 65 correctly solved the problem. From the entire sample of 150 students, there were 132 acts of student interaction with the problem that received a score of 1, and these are assigned a rank ($\frac{18+\dots+150}{132} = 84$). There were 17 acts of interaction (incorrectly solved problems) that have a rank ($\frac{1+\dots+17}{17} = 9$). Thus:

$$\begin{aligned} S &= 84 \cdot 67 + 5 \cdot 9 = 5673; \\ T_{obs} &= 5673 - \frac{72 \cdot 73}{2} = 3045; \\ W_{\alpha/2} &= \frac{72 \cdot 78}{2} + 1.64 \sqrt{\frac{72 \cdot 78 \cdot 151}{12}} = 3244; \\ T_{obs} &< W_{\alpha/2}. \end{aligned}$$

The accuracy and completeness of solving a standard problem were similarly assessed. For this problem $T_{obs} < W_{\alpha/2}$ as well. Therefore, in all cases of the standard problem, we have $T_{obs} < W_{\alpha/2}$. In all cases of problems with visualization, $T_{obs} > n_1 n_2 - W_{\alpha/2}$. Thus, we can conclude that the alternative hypothesis $H_1: P(X < Y) \neq \frac{1}{2}$ is accepted when rejecting the null hypothesis $H_0: P(X < Y) = \frac{1}{2}$. Acceptance of this hypothesis means that the analysis of experimental data allows us to conclude: the distribution laws of each group are different, indicating significantly better results for group E compared to group C. In other words, the experimental methodology improves the quality of performing standard tasks and also develops the ability to solve problems using visualization.

Considering the obtained results, the statistical significance of the differences between group E and group C was also evaluated using the Pearson χ^2 criterion (the difference in the distribution of residual knowledge and skills of groups E and C at the end of the experiment was determined). The null hypothesis was adopted: there is no difference between the two empirical distributions.

It was found that $\chi_{emp}^2 = 71.8$ and $\chi_{cr}^2 = 9.21$ ($\alpha = 0.01, v = 2$). Since $\chi_{emp}^2 > \chi_{cr}^2$, the null hypothesis is not accepted. Therefore, the difference in the total distribution of grades

for residual knowledge in higher mathematics in groups E and C is statistically significant, indicating differences between the residual knowledge in higher mathematics in the experimental and control groups. Thus, the level of formation of visual thinking in group E has significantly increased compared to group C, and these changes are statistically significant.

Thus, through mathematical methods of analyzing the results of an educational experiment, it was confirmed that there is an increase in the level of visual thinking formation and the level of mathematical preparation of students in experimental groups compared to students in the control group.

5. Conclusions

Visualization technology of educational information is a system that includes: a complex of educational knowledge; visual methods of their representation; visual-technical means of transmitting information; psychological techniques for using and developing visual thinking in the learning process. Visualization of educational material, conditioned by the development of information and communication technologies, provides the possibility of its compression, presentation as an orienting basis of action in a compact form, convenient for memorization and reproduction based on the learned associations and analogies. Visualization is associated with the formation of stable visual images and mastering various mental operations on them, similar to such general processes as abstraction, distinguishing the main from the secondary, structuring, logical reasoning, association, analogy, etc. Active and purposeful use of the reserves of visual thinking in the learning process is based on the selection of stable images in the educational material with an emphasis on the “primacy” of the image, on immediate and possibly more accurate visual association with an abstract concept that precedes verbal description. The essence of learning lies in shifting the priority from the illustrative function to the visual cognitive function, thereby ensuring the shift of emphasis from the educational function to the developmental one.

In this context, research was conducted on the problem of forming visual information and its visual perception in teaching higher mathematics, using examples of individual sections, as well as techniques of substantiation based on visual information. An analysis of the results of using visualization in the educational process of students at technical universities was conducted. The impact of visualization on the level of student knowledge in higher mathematics was analyzed.

In particular, it is noted the ability of a certain contingent of students to perceive and use visual images, their ability to think and express thoughts in images, to perceive the content of logic, emotions contained in visual information, as well as the ability to operate with visual images in communication, establish cause-and-effect relationships and relations between mathematical concepts, as well as memorize and reproduce representations of objects.

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