From cloud computing to quantum informatics: Advances in educational technology at CoSinE 2024

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Abstract

The 11th Illia O. Teplytskyi Workshop on Computer Simulation in Education (CoSinE 2024) brought together researchers exploring innovative applications of computer technologies in education. This paper presents an overview of the workshop's proceedings, comprising 10 peer-reviewed papers selected from 12 submissions. The contributions span diverse areas including cloud-based learning technologies, statistical education, quantum informatics, augmented reality, and digital linguistics. Notable themes include the integration of practical tools like R programming and GeoGebra, innovative approaches to STEM education, and the application of emerging technologies in teacher preparation. The workshop's hybrid format, hosted in Kryvyi Rih, Ukraine, facilitated global participation despite ongoing regional challenges, maintaining its tradition of fostering international collaboration in educational technology research.

Keywords

computer simulation, educational technology, STEM education, cloud computing, augmented reality, educational data mining, learning analytics, virtual learning environments, teacher education, quantum informatics

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1. Introduction

CoSinE (**Co**mputer **S**imulation **in** **E**ducation) is a peer-reviewed international workshop focusing on theory and practice of computer simulation in education.

The 11th Illia O. Teplytskyi Workshop on Computer Simulation in Education (CoSinE 2024) was a highly anticipated event that brings together researchers, educators, and practitioners from various fields to explore the latest advances and applications of computer technologies in education. Co-located with the XVI International Conference on Mathematics, Science and Technology Education (ICon-MaSTEd 2024), CoSinE 2024 will take place on May 15, 2024, in Kryvyi Rih, Ukraine, in a hybrid mode accommodating both in-person and online participants.

Figure 1: CoSinE logo.

The workshop is named after Illia O. Teplytskyi (1941–2018), a pioneering figure in the field of computer simulation in education [1], whose groundbreaking work has inspired and shaped the focus of this annual gathering. CoSinE has a rich history dating back to 2005, with previous editions held at prestigious institutions such as Kryvyi Rih State Pedagogical University, National Metallurgical Academy of Ukraine, Kryvyi Rih National University, Kherson State University, V.N. Karazin Kharkiv National University, and the Institute for Digitalisation of Education of the NAES of Ukraine.

One of the key aspects that sets CoSinE apart is its strong emphasis on real-world applications of computer simulation in education. The workshop encourages contributors to demonstrate the practical utility and impact of their proposed solutions, whether through case studies, experimental studies with usable learning applications, or surveys revealing new modeling tools in educational research and practice. This focus on tangible outcomes ensures that the insights and methodologies shared at CoSinE have the potential to directly enhance teaching and learning practices across various disciplines.

CoSinE topics of interest since 2019 [2, 3, 4, 5, 6] are:

- Computer simulation in STEM education
- AI in education
- Educational data mining and learning analytics
- Learning environments models
- Learning virtualization
- Modelling systems in education

This volume represents the proceedings of the 11th Illia O. Teplytskyi Workshop on Computer Simulation in Education (CoSinE 2024), held in Kryvyi Rih, Ukraine, on May 15, 2024. It comprises 10 contributed papers that were carefully peer-reviewed and selected from 12 submissions. Each submission was reviewed by 3 program committee members. The accepted papers present the state-of-the-art overview of successful cases and provides guidelines for future research.

2. Program committee

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3. Proceedings overview

The CoSinE 2024 proceedings showcase a diverse array of research contributions that push the boundaries of computer simulation in education. The article by Vakaliuk et al. [36] work on selecting cloud-based learning technologies for developing professional competencies of statistics majors exemplifies the workshop's focus on practical applications (figure 2). By defining evaluation criteria and applying expert evaluation, they identify the most suitable technologies for enhancing students' skills and readiness for the modern workforce.

Similarly, approach to teaching statistics to future programmers using real data sets and the R programming language proposed by Pavlenko et al. [37] aligns with CoSinE's emphasis on authentic learning experiences. By using data-driven tools and methodologies, they aim to increase students' motivation and equip them with valuable practical skills.

The application of data science tools in economics education, as explored by Rizun et al. [38], showcases the interdisciplinary nature of the research presented at CoSinE. Their demonstration of text mining and topic modeling techniques for analyzing public perception and opinion differences

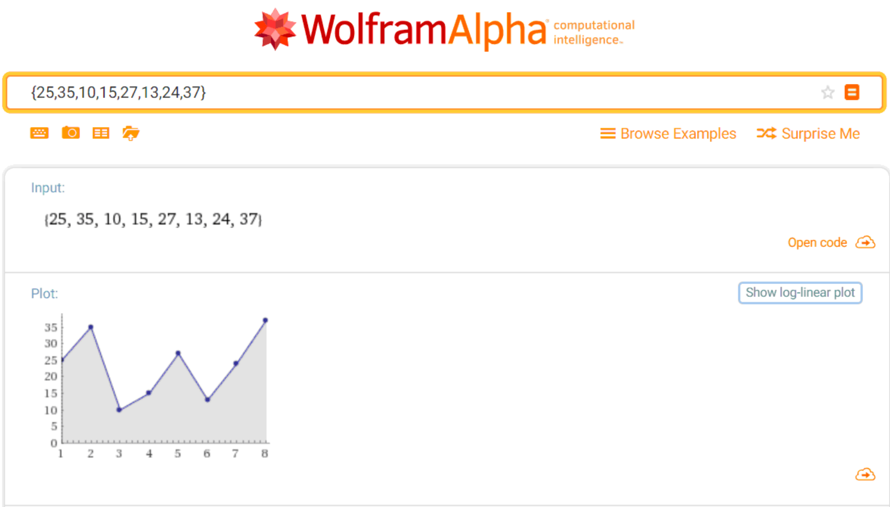

Figure 2: Cloud calculations in the Wolfram|Alpha service [36].

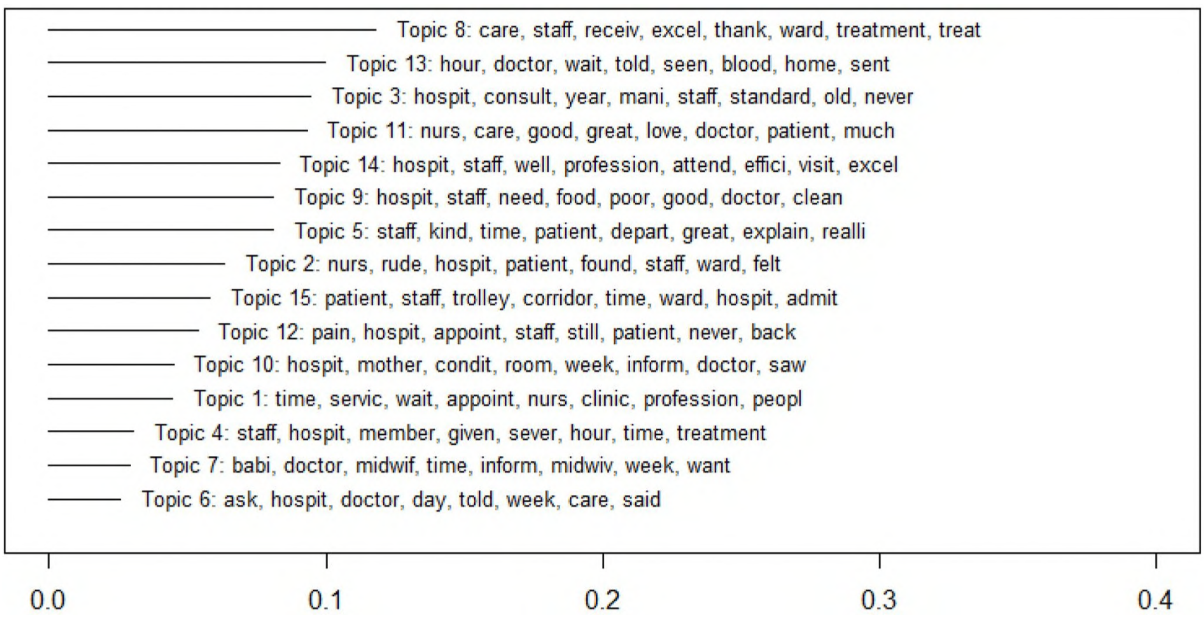

Figure 3: Expected topic proportions over corpus [38].

based on metadata highlights the potential of computational methods to shed light on complex social and economic phenomena (figure 3).

Beyond higher education, CoSinE 2024 also features research focused on school-level initiatives. Slipukhina et al. [39] analyse the distribution of STEM-STEAM-STREAM and Montessori pedagogy centers in Ukraine using web mapping data (figure 4). This research provides valuable insights into the landscape of innovative educational approaches in the country. By comparing the principles and didactic features of these approaches, they contribute to the ongoing discourse on effective teaching strategies.

The prospect of introducing quantum informatics in school courses, as discussed by Shokaliuk and Lehka [40], showcases CoSinE's commitment to exploring emerging areas of computer science education. Their proposal of an experimental content adapted for high school students, along with suggestions for software tools and Internet services (figure 5), lays the groundwork for future research and implementation efforts.

In the realm of mathematics education, Bilousova et al. [41] propose innovative approach to enhancing

Figure 4: STEM-STEAM-STREAM centers in Ukraine [39].

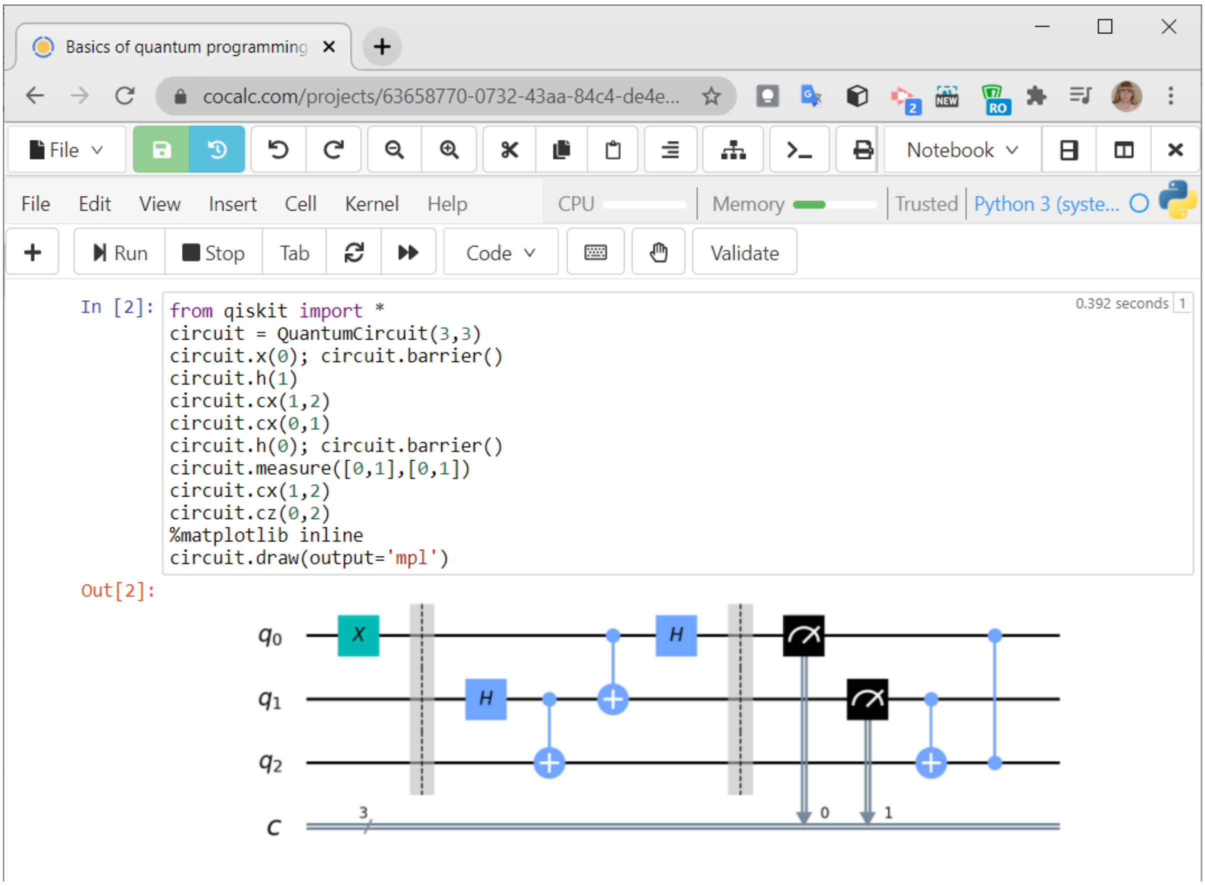

Figure 5: Jupyter notebook page in the CoCalc cloud environment [40].

mathematical understanding through dynamic GeoGebra modeling exemplifies the workshop's emphasis on holistic educational principles. Their comprehensive complex of models and supporting pedagogical framework demonstrate the potential of technology-enhanced learning to foster deeper conceptual understanding and engagement.

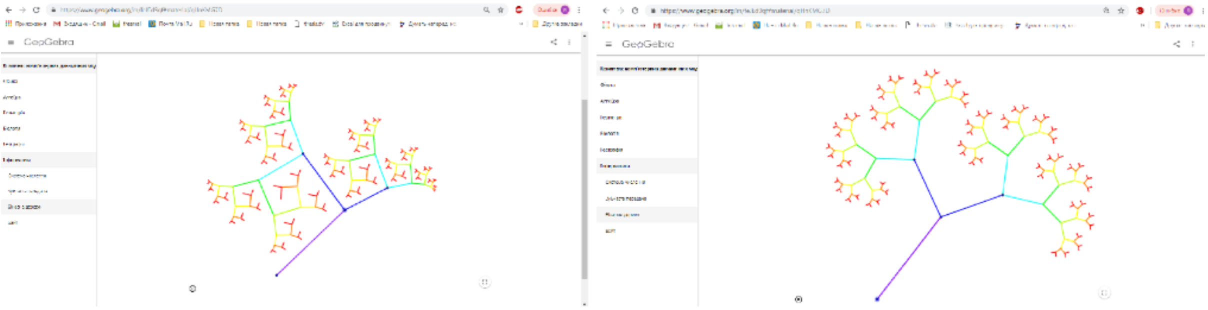

Figure 6: Fractal modelling in GeoGebra [41].

Several papers at CoSinE 2024 focus on the crucial task of preparing future computer science teachers. Oleksiuk et al. [42] propose model for the application and learning of cloud technologies, consisting of target, content, operational, and effective components (figure 7). This model provides a structured framework for integrating these technologies into teacher education programs. The stages of using cloud technologies and examples of implementation offer valuable guidance for educators and researchers alike.

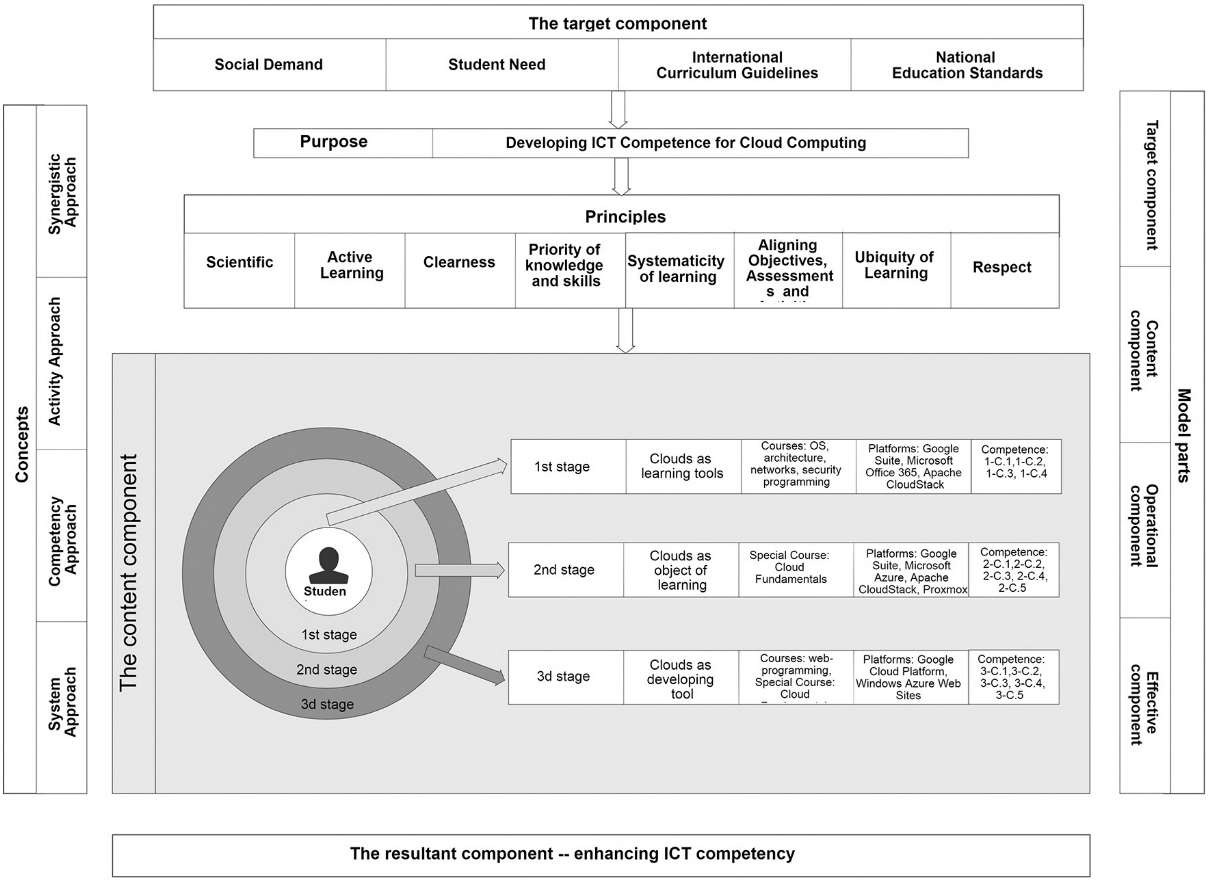

Figure 7: The model for learning cloud computing [42].

The use of ontologies for representing and designing subject domains in computer science education, as explored by Tsidylo and Kozibroda [43], represents another innovative approach showcased at

CoSinE. Their ontology schema (figure 8), criteria for selecting ontology systems, and methodology for constructing subject domain ontologies using the Protégé environment contribute to the growing body of knowledge on knowledge representation and management in educational contexts.

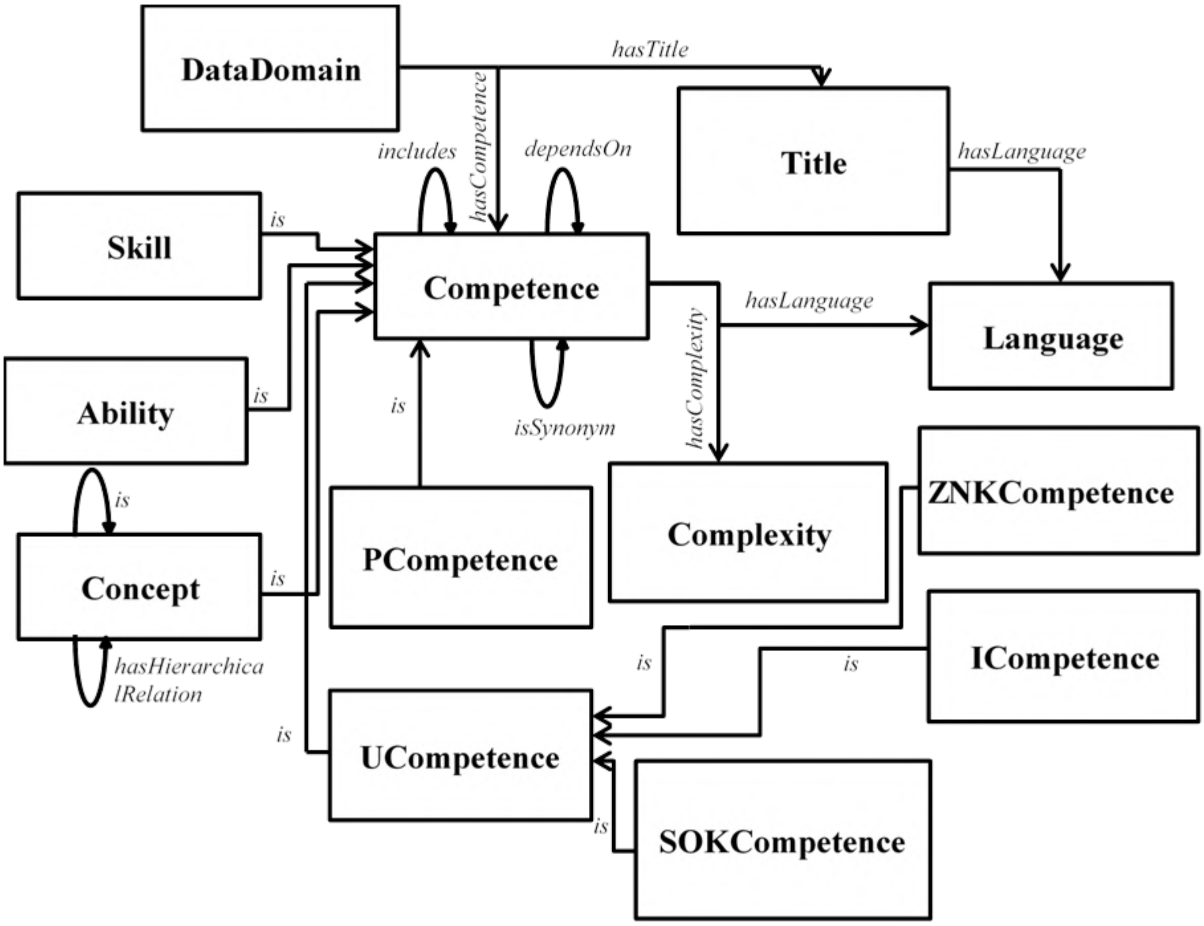

Figure 8: Ontology schema for subject domains [43].

Methodology for teaching the development of web-based augmented reality applications with integrated machine learning models developed by Semerikov et al. [44] highlights the workshop's focus on cutting-edge technologies and their educational applications. By detailing the technical implementation using WebAR tools, providing examples of created models (figure 9), and discussing the pedagogical aspects of their application, they offer a comprehensive framework for incorporating these advanced technologies into the curriculum.

Finally, linguistic perspective on emoji as an artificial digital language by Makhachashvili et al. [45] adds a unique dimension to the research presented at CoSinE. Their application of frame semantics to study the perception and interpretation of emoji signs contributes to the broader discourse on the role of digital communication in education and society (figure 10).

4. Conclusion

The papers presented at CoSinE 2024 collectively demonstrate the immense potential of computer simulation and related technologies to transform education across various domains and levels. The workshop's emphasis on real-world applications, interdisciplinary research, and innovative methodologies positions it as a vital platform for advancing the field and fostering collaboration among researchers, educators, and practitioners.

As the world continues to grapple with the challenges posed by the ongoing war in Ukraine, CoSinE

Figure 9: Face meshes [44].

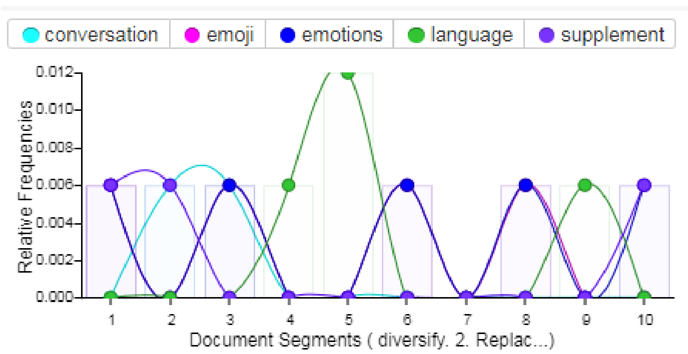

Figure 10: Digital content analysis: key words frequency [45].

2024's hybrid format ensures that the valuable insights and experiences shared by participants can reach a global audience, regardless of their ability to attend in person. The workshop's commitment to inclusivity and accessibility reflects the resilience and adaptability of the educational research community in the face of adversity.

We are grateful to all authors who submitted papers and to the delegates for their participation and interest in CoSinE as a platform for sharing their ideas and innovations. We also thank all program committee members for their continuous guidance and the efforts of peer reviewers who helped improve the quality of papers. The constructive criticism, improvements, and corrections provided to authors are greatly appreciated for their contribution to the success of the workshop. We hope all participants enjoy this conference and meet again in more peaceful, hilarious, and happiness of further CoSinE 2025.

Since CoSinE 2019, our workshop is **sponsored** by the CEUR Workshop Proceedings (CEUR-WS.org), the world's best Diamond Open-Access proceedings publisher for Computer Science workshops. Long live CEUR-WS.org!

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Selecting cloud-based learning technologies for developing professional competencies of bachelors majoring in statistics

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Abstract

Cloud-based learning technologies (CBLTs) are emerging as a promising way to facilitate the development of professional competencies of bachelors majoring in statistics. However, selecting the most suitable CBLTs for this purpose is not a trivial task, as it requires considering various criteria and evaluating the available options. In this article, we propose a systematic approach to select CBLTs for the formation of professional competencies of bachelors majoring in statistics, based on three main criteria: information-didactic, functional, and technological. We apply the method of expert evaluation to assess the existing CBLTs according to these criteria and identify the most appropriate ones for the educational process. We also describe the general structure of the methodology of using CBLTs for the formation of professional competencies of future bachelors of statistics. The results of our study show that CoCalc and Wolfram|Alpha are the most convenient and effective CBLTs for this purpose, as they exhibit high performance on all criteria.

Keywords

cloud-based learning technologies, professional competencies, statistics education, expert evaluation

1. Introduction

The rapid development of information and communication technologies (ICTs) has brought significant changes to various spheres of human activity, including education. In particular, the emergence of cloud computing and cloud-based learning technologies (CBLTs) has opened new opportunities for enhancing the quality and effectiveness of education, as well as for facilitating the development of professional competencies of future specialists [1, 2, 3, 4, 5, 6, 7, 8]. However, selecting and applying CBLTs for specific educational purposes is not a straightforward task, as it requires taking into account various criteria and evaluating the available options. In this paper, we focus on the problem of selecting CBLTs for the formation of professional competencies of bachelors majoring in statistics, which is an important and relevant field of study in the context of European integration and data-driven society.

Statistics is a branch of mathematics that deals with the collection, analysis, interpretation, and presentation of data. Statistics is widely used in various domains, such as science, engineering, business, economics, social sciences, health, and education. Statistics helps to understand the patterns and trends in data, to test hypotheses and make predictions, to support decision making and problem solving, and to communicate findings and conclusions. Therefore, statistics education is essential for preparing future specialists who can effectively use data in their professional activities.

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The formation of professional competencies of bachelors majoring in statistics involves acquiring both theoretical knowledge and practical skills in statistics, as well as developing critical thinking, creativity, communication, collaboration, and self-regulation abilities. To achieve these learning outcomes, it is necessary to use appropriate learning technologies that can support the learners' engagement, motivation, feedback, reflection, and collaboration. Moreover, it is desirable to use learning technologies that can provide access to various statistical tools and resources, such as software packages, databases, datasets, online calculators, simulators, visualizers, etc.

CBLTs are learning technologies that are based on cloud computing, which is a model of providing on-demand access to a shared pool of configurable computing resources (such as servers, networks, storage, applications, and services) over the Internet [9]. CBLTs offer several benefits for education [10], such as:

- *Scalability*: CBLTs can dynamically adjust the amount of resources according to the demand and load.
- *Availability*: CBLTs can be accessed anytime and anywhere via the Internet using various devices (such as computers, tablets, smartphones, etc.).
- *Cost-effectiveness*: CBLTs can reduce the costs of acquiring, maintaining, and updating hardware and software resources.
- *Collaboration*: CBLTs can facilitate the collaboration among learners and teachers by providing tools for sharing data and documents, communicating via text or voice or video chat, co-editing files or code or formulas or graphs etc.
- *Innovation*: CBLTs can enable the creation and delivery of new types of learning activities and content that are not possible with traditional learning technologies.

However, not all CBLTs are equally suitable for the formation of professional competencies of bachelors majoring in statistics. Therefore, it is important to have a systematic approach to select the most appropriate CBLTs for this purpose. In this paper, we propose such an approach based on three main criteria: information-didactic, functional, and technological. We also apply the method of expert evaluation to assess the existing CBLTs according to these criteria and identify the most appropriate ones for the educational process. We also describe the general structure of the methodology of using CBLTs for the formation of professional competencies of future bachelors of statistics.

2. Methods

An expert evaluation method was used to implement the selection of the CBLT for the formation of the professional competencies of future bachelors of statistics and for effective application in the process of forming the corresponding competencies [11, 12]. According to the purpose and objectives of the method, the corresponding CBLT is numbered in ascending or descending order based on a separate trait, by which further ranking is made. It should be noted that the peer review was carried out in two stages.

In the first stage, experts were asked to evaluate 8 CBLT that could be used in the process of forming the professional competencies of future bachelors of statistics.

In the second phase of the study, another group of specialists was recruited to evaluate the most significant CBLT according to certain criteria.

3. Results

3.1. Selection of cloud-based learning technologies for the formation of professional competencies of future bachelors of statistics

Research on the implementation of cloud-based learning technologies to shape the professional competencies of future professionals is being actively pursued by various researchers. As this research is aimed at CBLT to shape the professional competencies of future Bachelor of Statistics, it is important to identify, by a certain set of criteria, the most effective, convenient, and relevant cloud-based learning technologies to be used in the educational process of HEI.

To begin with, we will define the term "criteria", since this definition is presented differently by different researchers.

In encyclopedic reference publications, the concept of "criterion" is defined as "a trait, a basis for evaluation, taken as a basis for classification" [13].

In [14] the criterion is called "the criterion for evaluating something, a means of verifying the truth or falsehood of a statement".

Bagrii [15] argues that the criterion is "a standard against which to evaluate, compare a real pedagogical phenomenon, process, or quality by reference".

Torchevsky [16] notes that "in the most general form, the criterion is an important and defining feature that characterizes the various qualitative aspects of a particular phenomenon under study, helps to clarify its essence, helps to specify the main manifestations. In this regard, the indicator is a quantitative characteristic of this phenomenon under study, which makes it possible to conclude on the state of statics and dynamics".

In Dychkivska [17] term "criterion" is defined as "an indicator that characterizes the property (quality) of an object, the evaluation of which is possible using one of the measurement methods or the expert method".

Under the selection criteria of CBLT for the formation of professional competencies of future bachelors of statistics, we will understand such features, qualities, and properties of cloud-based technologies that are required for their effective use in the educational process to form the professional competencies of future bachelors of statistics.

We apply the method of expert evaluation [11, 12]. In the first stage, experts were asked to evaluate 8 CBLT that could be used in the process of forming the professional competencies of future bachelors of statistics.

20 experts of different profiles were invited to the expert evaluation procedure, among them officials of the State Statistical Service of Ukraine and the State Treasury in Zhytomyr, employees of banking institutions, employees of commercial financial institutions.

A point scoring system was used in the study [18]. According to the aforementioned evaluation system, for the number of N CBLT, the maximum possible estimate of N is given to the most significant in the use of CBLT and 1 to the least significant. The results of the assessment are presented in the form of a table, where the columns indicate the hotline number and the fields the expert number. The CBLT name card is presented in alphabetical order (A to Z), to prevent psychological clues that could affect the outcome of the assessment.

To determine whether there is an objective agreement between experts, calculated Kendall's Concordance Coefficient W [11, 12] by the appropriate formula specified in [11, 12].

The results of the peer review are presented in table 1.

Four CBLT 4 were selected: CoCalc, Scilab, WebMathematica, Wolfram|Alpha.

After calculating based on the experimental data presented (table 1), obtained a coefficient of concordance $W = 0.71$. Since the value obtained is non-zero, there is an objective agreement between experts.

In the second phase of the study, another group of specialists was recruited to evaluate the most significant CBLT according to certain criteria. It is worth noting that the second stage involved 15 specialists of different profiles, namely: teachers, heads of departments and deans of faculties of higher education institutions of Ukraine, having experience and related to the professional training of future bachelors of statistics, employers (Main Department of Statistics in Zhytomyr region, Department of the State Treasury Service of Ukraine in Zhytomyr, Main Department of State Tax Service in Zhytomyr region, heads of state and commercial banks, managers financial companies), which worked directly with the selected CBLT and could objectively evaluate them according to the degree of manifestation of each criterion.

Table 1
Ranking cloud-based learning technologies for the formation of the professional competencies of future bachelor of statistics.

Expert number	CBLT							
	CoCalc	Excel Online	GeoGebra	Google Sheets	Maple Cloud	Scilab	Web Mathematica	Wolfram| Alpha
1	6	4	2	1	3	5	7	8
2	6	5	1	2	3	4	8	7
3	8	1	2	3	4	5	7	6
4	5	3	2	1	4	8	7	6
5	5	2	1	4	3	6	7	8
6	6	1	5	2	3	4	8	7
7	8	2	3	1	5	4	7	6
8	5	3	1	2	4	6	7	8
9	6	1	4	3	2	5	8	7
10	7	1	2	3	4	8	5	6
11	7	3	2	4	1	6	5	8
12	5	2	3	6	1	4	8	7
13	8	1	2	3	4	5	6	7
14	6	4	1	3	2	5	8	7
15	7	4	1	3	2	5	6	8
16	5	3	2	4	1	6	8	7
17	8	2	1	3	5	4	7	6
18	7	1	2	3	4	8	5	6
19	4	3	2	1	8	7	5	6
20	7	4	1	2	3	6	5	8
S	126	50	40	54	66	111	134	139
d	36	-40	-50	-36	-24	21	44	49

The manifestation of each of the presented criteria was evaluated for each of CBLT. To this end, experts have been asked to evaluate its performance using the scale shown in table 2.

Table 2
Scale bar for evaluation of the relevant criteria.

Scores	Evaluation of the indicator
0	the indicator is missing
1	the indicator is partially available (not available more than available)
2	the indicator is more available than not available
3	the indicator is completely available

The indicator will be considered positive if the arithmetic mean of these points is at least 1.5. If more than half (50%) of the indicators of the relevant criterion are negative, then the criterion is defined as insufficiently developed. In the case of:

- when 50–55% of the indicators of the criterion are positive, the criterion is characterized as critically manifested;
- if 56–75% of the indicators of the criterion are positive, then the criterion is characterized as sufficiently manifested;
- if 76–100% of the criterion indicators are positive, then the criterion is characterized as highly manifested [18].

An analysis of existing cloud-based learning technologies to shape the professional competencies of future bachelors of statistics has made it possible to identify the criteria and relevant indicators of these cloud-based learning technologies:

- information-didactic: information support; coverage of various sections of mathematics and statistics; graphical presentation of results; teamwork on the project; ability to apply programming knowledge;
- functional: user-friendly interface; free of charge; accessibility; multilingualism;
- technological: cross-platform; integration with other cloud services; adaptability.

The results of the peer review of each of the selected criteria and relevant indicators will be discussed in more detail.

The information-didactic criterion characterizes the information and didactic component of cloud-based learning technology and is based on the laws of assimilation of knowledge, skills, and competences, namely:

- the indicator "information support" characterizes the presence of a description of the use of the tool, examples, or the presence of a section of assistance;
- the indicator "coverage of various sections of mathematics and statistics" characterizes the possibility of using CBLT in the process of studying certain sections of mathematics and statistics;
- the indicator "graphical presentation of results" characterizes the ability to interpret the results in the form of graphs, histograms, or a three-dimensional model;
- the indicator "teamwork on the project" characterizes the ability to work with multiple users at the same time;
- the indicator "ability to apply programming knowledge" characterizes the ability to take individual actions to perform calculations using different programming languages.

Basic data on indicators of information-didactic criteria for each of the selected CBLT are shown in table 3.

Table 3
The information-didactic criterion for selection of cloud-based learning technologies and the value of its indicators.

CBLT	The indicators						
	Information support	Coverage of various sections of mathematics and statistics	Graphical presentation of results	Teamwork on the project	Ability to apply programming knowledge	The manifestation of the criterion	The level of manifestation
CoCalc	1.93	2.67	2.07	1.80	2.00	100%	highly
Scilab	2.13	2.20	0.80	0.80	2.33	60%	sufficiently
WebMathematica	1.47	2.00	1.33	1.53	2.13	80%	highly
Wolfram|Alpha	2.33	2.27	2.33	1.53	2.33	100%	highly

The functional criterion characterizes the functional component of cloud-based learning technologies and assumes the following indicators:

- the indicator "user-friendly interface" describes the convenience and comprehensibility of the interface and the computational component of the software system;
- the indicator "accessibility" characterizes the provision of cloud-based learning technology to different categories of users;
- the indicator "free of charge" characterizes the possibility of free or full use of cloud-based learning technologies;
- the indicator "multilingualism" characterizes the support of multiple languages (localization) of the interface.

Table 4
The functional criterion for the selection of cloud-based learning technologies and the value of its indicators.

CBLT	The indicators					
	User-friendly interface	Free of charge	Accessibility	Multilingualism	The manifestation of the criterion	The level of manifestation
CoCalc	1.80	2.00	2.20	1.80	100%	highly
Scilab	2.00	1.87	2.13	1.53	100%	highly
WebMathematica	1.73	1.87	1.73	1.93	100%	highly
Wolfram Alpha	2.13	2.53	2.20	1.60	100%	highly

The basic data on the indicators of the functional criterion for each of the selected CBLT are shown in table 4.

The technological criterion is characterized as follows:

- "cross-platform" indicates the possibility of using cloud-based learning technologies in different operating systems;
- the indicator "integration with other cloud services" implies the possibility of supporting the work with calculations in different cloud services, and the possibility of further integration with other services;
- "adaptability" indicates the possibility of full use of cloud-based learning technologies on different devices (desktop computer, notebook, tablet, smartphone, etc.).

The basic data on the indicators of the technological criterion for each of the selected CBLT presented in table 5.

Table 5
The technological criterion for the selection of cloud-based learning technologies and the value of its indicators.

CBLT	The indicators				
	Cross-platform	Integration with other cloud services	Adaptability	The manifestation of the criterion	The level of manifestation
CoCalc	1.53	1.53	1.93	100%	highly
Scilab	1.53	1.53	1.53	100%	highly
WebMathematica	1.73	1.73	1.93	100%	highly
Wolfram Alpha	2.60	2.33	2.93	100%	highly

Let's summarize the results of the study in table 6.

Table 6
Generalized results of the selection of cloud-based learning technologies by the manifestation of all criteria

CBLT	Criterion		
	Information-didactic	Functional	Technological
CoCalc	100%	100%	100%
Scilab	60%	100%	100%
WebMathematica	80%	100%	100%
Wolfram Alpha	100%	100%	100%

3.2. The general structure of the methodology of using cloud-based learning technologies for the formation of professional competencies of future bachelors of statistics

The formation of professional competencies is a long process that requires, in addition to appropriate teacher training, the use of appropriate methods of its implementation.

The methodology of using cloud-based learning technologies for the formation of professional competencies of future bachelors of statistics includes the purpose of the application, the content of an application, interrelated forms of training, methods, and tools for achieving a predictable result.

The expected result of the methodology is the formed professional competencies of future bachelors of statistics in the specialty 112 “Statistics”.

The purpose of using cloud-based learning technologies is to form in future bachelors’ statistics of professional competencies.

The content of the methodology involves improving the learning process of disciplines of general training of the variable part of the free choice of students using cloud-based learning technologies (on the example of the content of the variable discipline of “Computer Statistics”).

Note the features of teaching the discipline “Computer Statistics” for the training of future bachelors of statistics using cloud-based learning technologies.

To improve and enhance the discipline “Computer Statistics” carried out:

- selection of cloud-based learning technologies that are appropriate and reasonable to use in the learning process of future bachelors of statistics, to form their professional competencies;
- improving the content of the variable discipline “Computer Statistics” for the use of cloud-based learning technologies during the acquaintance and mastery of relevant topics of the course;
- development of methodical recommendations on the use of cloud-based learning technologies in the educational process of the discipline “Computer Statistics”.

The purpose of the discipline is based on the mastery of practical skills of future professional activity in conditions that are as close as possible to the real ones; to form professional competencies in applicants related to a thorough knowledge of the chosen field of statistics, the ability to perform a qualitative analysis of data or calculations, calculations of relevant processes, the ability to work with statistical information, the use of appropriate software and cloud services, able to work both independently and in a team.

The study of the discipline “Computer Statistics” assumes that applicants for the specialty 112 “Statistics” must *know* the:

- basic concepts of mathematical statistics;
- stages of statistical research;
- specialized programming languages, in particular, the statistical programming language R;
- software for working with statistical data;
- specialized cloud services for organizing work with statistical information;
- features of the organization of joint work using cloud services;

be able to:

- perform statistical calculations;
- perform statistical calculations using specialized software;
- perform statistical calculations using appropriate cloud services;
- transmit and receive statistics;
- analyze the obtained data;
- build and edit schedules;
- visualize the received data with the help of specialized cloud services;

- organize joint activities with other specialists of the relevant activity or clients for whom the statistical survey is carried out.

Consider the modules that form the content of the advanced program of the discipline "Computer Statistics":

Module 1. Working with data. Basics of work in R.
Content module 1. Basic concepts, data types, and elementary functions. Arithmetic and logical operations. Basic mathematical functions. Vectors. Matrices. Arrays and data frames.
Content module 2. Export and import of data in R. Export of data, import of data in internal format. Export and import data tables.
Content module 3. Programming in R. Creating your functions. The technique of vectorization of the function. Conditional use (if) and multi-conditional (switch) operations. While and repeat loops. Cycle for.

Module 2. Basic concepts of statistical distribution.
Content module 4. Basic probability distributions. General concepts of distribution. The most commonly used distributions.
Content module 5. Graphic representation of statistical distributions. Points on the plane. Charts. Construction of histograms. Elements of three-dimensional graphics.

Module 3. Statistical evaluation and statistical testing of hypotheses.
Content module 6. Evaluation of unknown parameters. The method of moments. Quantile method. The method of the highest probability. Confidence intervals.
Content module 7. Test of statistical hypotheses. General concepts of the theory of hypothesis testing. Algorithm for testing statistical hypotheses. Pearson's criterion. Kolmogorov's criterion.

The proposed technique involves the use of the following teaching methods of selected cloud-based learning technologies (CoCalc and Wolfram|Alpha, as described above and in [12]):

- *Explanatory and illustrative.* Statistics as a science is quite complex and contains many sections that contain a significant amount of theoretical material, theorems and proofs, formulas, and graphical constructions of relevant processes. The explanatory-illustrative method as the most appropriate to use because students receive accurate theoretical material from the teacher, or independently from the textbook or textbook with subsequent discussion in class or online, and receive a visual presentation of the material using selected cloud-based learning technologies, demonstration of practical application cloud-based learning technologies CoCalc and Wolfram|Alpha (figure 1). Explaining the theoretical aspects of statistics is a basic factor influencing students' further understanding of the following related topics in the course, the use of cloud-based learning technologies to effectively perform professional tasks and the formation of professional competencies of future bachelors of statistics.
- *Reproductive.* Given the accuracy and complexity of the theoretical material, the course of the discipline "Computer Statistics" provides for laboratory and practical work, which is planned to practice tasks of varying complexity according to the specified algorithm according to the relevant educational topic, as well as a demonstration of their cloud-based learning technologies. CoCalc and Wolfram|Alpha followed by a repetition of the action scenario by the students. It is planned to present ready-made solved exercises and perform exercises in a similar way (two or three exercises or tasks). Also, it can be pre-prepared by the teacher sets of statistics provided to students as a separate file in the cloud storage or ready-presented statistical sets presented on the MEI page (Mathematics Education Innovation, http://mei.org.uk/data-sets), or on Google Public Data, Google Dataset Search services.
- The method of *problem statement* can be effectively used during practical or independent work, during which students do not receive samples of problem-solving or ready-made algorithms for working with cloud-based learning technologies. The teacher describes the problems or asks the

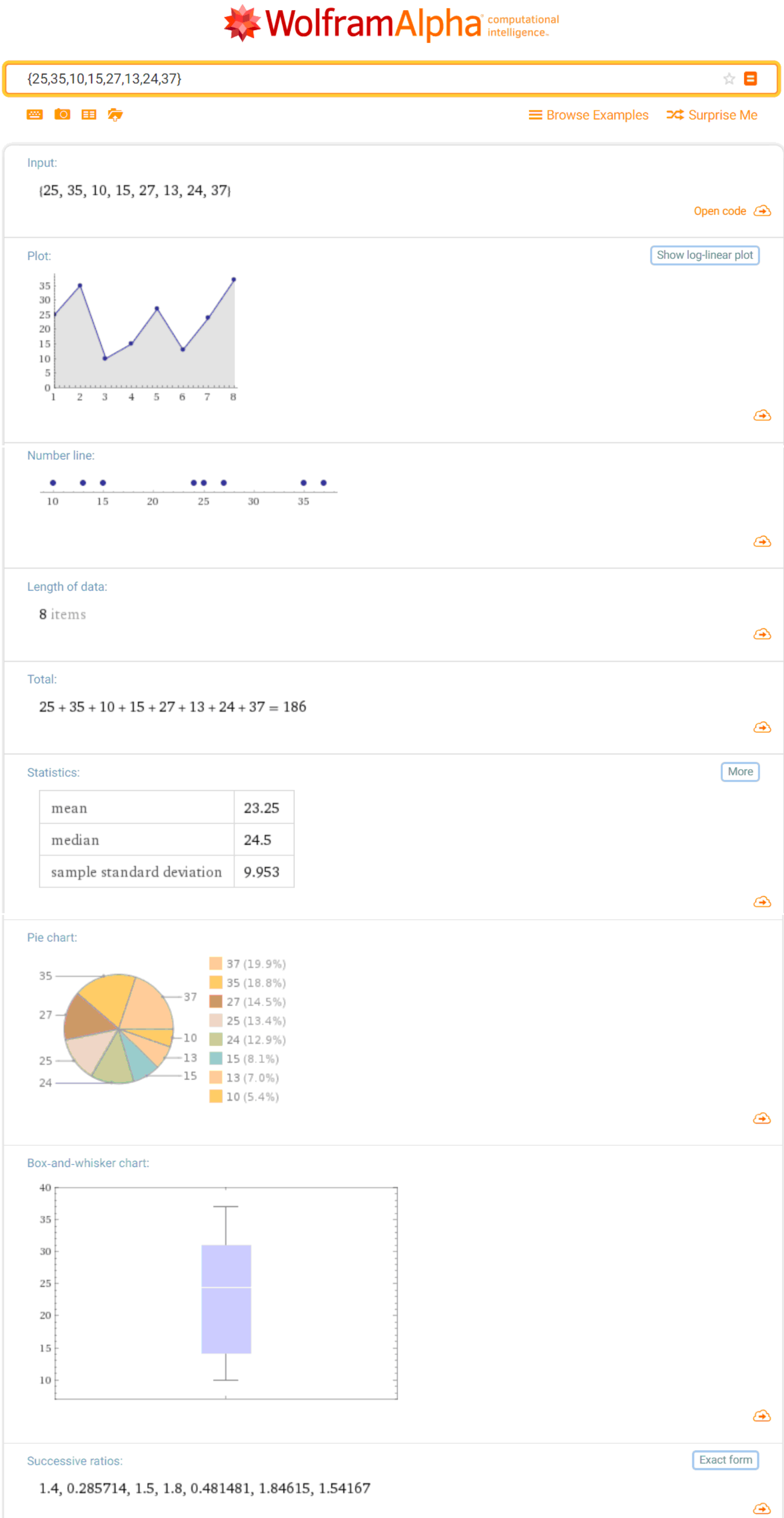

Figure 1: The result of sampling calculations in the Wolfram|Alpha service.

formed problem question (one or more), describes the ways to solve the problem, acts as a mentor who guides the work of students. Working in such circumstances promotes the development of students' critical thinking, solving atypical situations, and forms professional competencies, in particular, to develop research and analyze the data obtained; ability to present the results to the target audience; ability to work in a team.

- *Partial search.* The study material is presented by the teacher in part (a certain part of the topic), and the rest of the students work independently. However, the teacher directs the work of applicants with questions or pre-selected tasks to prevent errors in their activities or found the wrong solution.
- *Research.* The method is quite difficult to use because it requires additional training from the teacher and is quite time-consuming. Provides independence of students in the study of a particular topic or theoretical aspect, its practical implementation in cloud-based learning technologies CoCalc, Wolfram|Alpha, or the study of additional topics related to the topic of the course, but not considered due to time constraints on learning discipline. Researching the problem develops the ability to conduct research, the ability to use hardware and specialized cloud services, obtain additional data and interpret them, the ability to work independently, all together are components of professional competencies formed at the appropriate level of a successful future statistician.

The means of forming the professional competencies of future bachelors of statistics, which are specified in the presented methodology using cloud-based learning technologies, include CoCalc and Wolfram|Alpha, textbooks or teaching materials, as well as computers (laptops, tablets, smartphones) with an active connection to the Internet.

The result of the proposed methodology is the formed professional competencies of future bachelors of statistics at a high level, as well as the successful application of skills to use CoCalc and Wolfram|Alpha to perform practical work in the professional field.

4. Conclusions

In this paper, we have proposed a systematic approach to select cloud-based learning technologies (CBLTs) for the formation of professional competencies of bachelors majoring in statistics. We have defined three main criteria for selecting CBLTs: information-didactic, functional, and technological. We have applied the method of expert evaluation to assess the existing CBLTs according to these criteria and identify the most appropriate ones for the educational process. We have also outlined the general structure of the methodology of using CBLTs for the formation of professional competencies of future bachelors of statistics.

The results of our study show that CoCalc and Wolfram|Alpha are the most convenient and effective CBLTs for the formation of professional competencies of bachelors majoring in statistics, as they exhibit high performance on all criteria. CoCalc is a cloud-based platform that provides access to various open-source software packages for mathematics, science, and engineering, such as SageMath, Python, R, Julia, etc. Wolfram|Alpha is a cloud-based computational knowledge engine that can answer factual queries, perform calculations, generate plots, and provide step-by-step solutions. Both CBLTs can support the learners' engagement, motivation, feedback, reflection, and collaboration, as well as provide them with various statistical tools and resources.

The general structure of the methodology of using CBLTs for the formation of professional competencies of future bachelors of statistics consists of four main components: objectives, content, forms, and methods. The objectives define the expected learning outcomes and competencies that the learners should acquire by using CBLTs. The content specifies the topics and tasks that the learners should cover and complete by using CBLTs. The forms describe the ways of organizing the educational process by using CBLTs, such as individual work, group work, project work, etc. The methods describe the techniques and strategies that the learners and teachers should use to facilitate the learning process by using CBLTs, such as problem-based learning, inquiry-based learning, collaborative learning, etc.

As a direction for future work, we plan to elaborate on each component of the methodology of using CBLTs for the formation of professional competencies of future bachelors of statistics. We also intend to conduct an empirical study to evaluate the effectiveness and efficiency of our proposed approach and methodology.

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Analyzing the distribution of STEM-STEAM-STREAM and Montessori pedagogy centers in Ukraine

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Abstract

The authors of this paper have analyzed the distribution of educational institutions in Ukraine that use the STEM-STEAM-STREAM approach and methodological tools of M. Montessori pedagogy. The authors used Google Maps to search, identify and quantitatively analyze the distribution of these institutions. The results of data processing are presented in the form of author's maps and diagrams, which indicate the number of Montessori pedagogy centers and STEM-STEAM-STREAM training centers for each region. The authors also analyzed the content and organization of some Montessori centers in Ukraine based on the data of the official websites of educational institutions. The authors used the method of Gartner Hype Cycle to obtain a conclusion about the state of development of pedagogical technologies. Comparison of the principles of pedagogy M. Montessori and STEM approach to education reveals many common didactic features based on the ideas of constructivism in education. In particular, the authors note the features of active interaction of subjects of the educational process, the development of curiosity, change of the teacher functions.

Keywords

STEM-STEAM-STREAM, Montessori pedagogy, constructivism, Gartner Hype Cycle, education, Ukraine

1. Introduction

The rapid changes and challenges of the 21st century require the society to foster the skills and readiness of individuals for successful socialization and adaptation. This leads to the development of variable education in Ukraine, which is reflected in the reform of education at all levels. The autonomy of educational institutions [1] enables the provision of educational services based on a variety of innovative programs and methods. One of the popular and supported by the state [2] approaches in the educational environment is STEM [3, 4, 5, 6, 7], which integrates science, technology, engineering, and mathematics.

The pedagogical system of M. Montessori [8] is recognized as a classic innovative technology of education for children from the early age, which is evidenced by the existence of numerous pedagogical centers. The Montessori approach adheres to the principles of humanitarian pedagogy: the child's personality with all its individuality, similarity and difference from other children is the focus of the educational process [9].

However, the pedagogical challenge of early identification and development of engineering abilities is particularly relevant in the era of fast-paced development of tools and technologies. In this context, innovative learning technologies, such as the STEM approach in education [10, 11], are expected to provide significant assistance.

The emergence of educational centers in Ukraine is a result of the demand of the society and the state. How relevant is M. Montessori's pedagogical technology for domestic educational institutions compared to the STEM-STEAM-STREAM approach? What are the commonalities and differences between these

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pedagogical systems? Up-to-date data for the answers can be obtained through the use of web mapping service tools Google Maps.

2. Related work

Almost 120 years of implementation of Montessori pedagogical ideas around the world are reflected in numerous scientific works [12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41]. The ideas also prove the relevance in the 21st century: from the earliest works on the introduction of Montessori methods as a didactic tool for speech development of preschool children and teaching them to read and write [8], through the study of sensory and motor skills, game techniques to stimulate communicative activity of preschoolers as a basis of speech skills. The need for integrative techniques based on the STREAM approach is revealed in the work of Krutiy and Hrytsyshyna [10]. Mavric [9] emphasizes on the importance of pedagogical ideas of M. Montessori for educational systems of the 21st century exploring the didactic aspects of personalized instructions; in particular, she points to the dual role of the teacher as "knowledge facilitator who offers advice and is a training specialist" at the same time. The same work shows the best academic results of the pupils comparatively to other public or private primary schools, in particular, in mathematics and physics [9]. Essential for the Montessori teaching method is the dynamic interaction of the triad "child, teacher, environment (prepared situations)". Remarkable is comprehension of the Montessori Method proposed by Marshall [11] in the context of two important aspects: educational materials and the way in which the teacher and the design of the prepared environment promote independent interaction of children with these materials. It also draws attention to confirmed over time significant adaptability of the method.

On the other hand, socio-economic processes and challenges of the 21st century determine the problem of high-quality technical and technological teaching of the younger generation: the STEM abbreviation is actively used in all spheres of our life to describe processes in the agro-industrial complex, medicine, energy, robotics, IT market, transport, industry, and, above all, in education [42, 43].

The abbreviation STEAM (Science, Technology, Engineering, Arts / All, and Mathematics) is widely used nowadays to indicate that the technology is used to study not only technical sciences but also arty disciplines, for example, industrial aesthetics, industrial design, 3D modeling, architecture, cinema [44, 45]. Another important area is the STREAM approach in education (Science, Technology, Reading + WRiting, Engineering, Arts and Mathematics) aimed at early education of the culture of engineering thinking and the formation of pupils' skills in technology, science, reading and writing, engineering , art and mathematics. This approach is intended to form critical thinking of preschool and primary school children; according to the age characteristics, mainly emotions are used to motivate the children to learn [10]. In general, the key aim of STEM-STEAM-STREAM approaches to curriculum development is to expand the consciousness of participants of the educational process, help to actively respond to changes in reality but not "direct transfer" of knowledge [2].

At the same time, according to Lapon [46], the methods based on the ideas of M. Montessori are focused on the education of respect for learning, encouraging the child's curiosity through realistic experience, creativity and self-understanding.

In order to determine the probable "points of contact" of the STEM / STREAM approach and M. Montessori's methodology, we will consider their peculiarities of educational process. According to the description of Dychkivska and Ponymanska [8], M. Montessori's method is aimed at studying five aspects of life: practical life skills, sensory, mathematics, speech development (reading and writing), space education (history, time, nature). The child's independence and freedom is at the center. Possibility for pupils to make mistakes, analyze them, seek help from more experienced pupils or the teacher. This technique effectively encourages the development of critical thinking and forms the skills of finding creative approaches to problems solving [46].

A long time of research and practical implementation of methods based on the ideas of M. Montessori showed that it is most effective at the early stages of child development. This leads to the assumption about its similarity with STEM and STREAM approaches aimed at early career guidance of new generations, deepening skills, creating opportunities for research work, conducting scientific and technical activities and more.

3. Research methods

The *aim* of the article is to clarify the roots of common features of Montessori pedagogy and teaching methods based on the STEM-STEAM-STREAM approach. Subsequent aim is a comparison of their applicability in the educational space of Ukraine based on data web mapping service Google Maps.

To compare educational technologies in Montessori schools and STEM-STEAM-STREAM educational centers, the analysis of scientific literature and data from open sources is used, which demonstrate the current practical aspects of the implementation of these methods in Ukraine.

An important indicator of the activity of the use of the above mentioned innovative learning technologies is the public demand for running of the related centers of education. For this purpose, the search and identification by means of the web mapping service of the Google Maps system was used. An example of the result of such a search is shown in figure 1; it demonstrates a screenshot of the Google Maps application for a search inquiry for the keywords "Zhytomyr Montessori School", "Zhytomyr Montessori Kindergarten", "Montessori Zhytomyr".

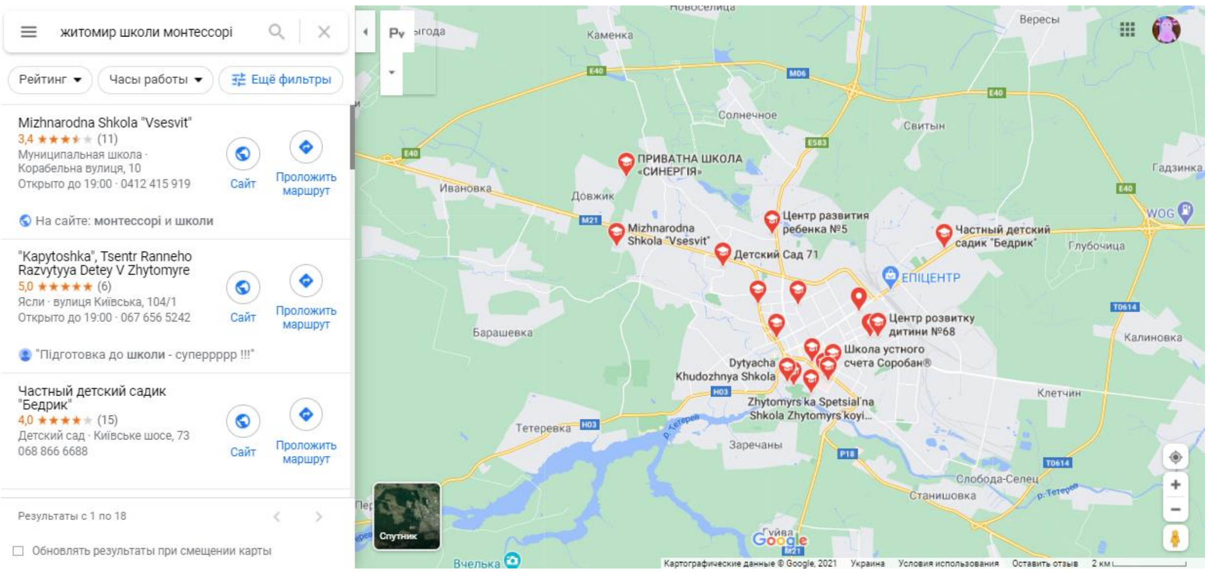

Figure 1: Search for Montessori centers in the city of Zhytomyr using the search and mapping service Google Maps.

4. Results and discussion

Comparisons of the system of free education of M. Montessori and STREAM-approach in education reveal many common features, in particular:

- focus on the formation of certain skills, their conjunction with knowledge of the world around, self-awareness and own role in society;
- the possibility of effective implementation of these technologies at all stages of child development;
- joint activities of teacher and pupil aimed at solving practically significant problems;
- use of acquired skills in everyday life with an approximation for future professional activity;
- promoting communication and team spirit;
- development of interest to certain actions, subjects, and the process of new knowledge obtaining;

- introduction of creative and innovative approaches in the educational process;
- preparing the student for future successful socialization and the formation of lifelong learning skills.

4.1. The paradigm of constructivism in education as the basis of similarity of methods

The similarity of these pedagogical technologies, the implementation of which separates 100 years, should be evaluated as a practical embodiment of the constructivist paradigm of education; its origins are in the interdisciplinary field of philosophy, psychology, sociology and education [47]. Note that the development of constructivism as an evolutionary epistemology began with the works of von Glasersfeld [48], Piaget [49], Vygotsky [50] and others. The main idea of this philosophical trend in the context of learning and teaching concerns the mutual influence of participants of the educational process and learning environment [51]: knowledge is formed through active social interaction and communication where shared experience is developed; learner builds during the learning process a new understanding and concept of the learning environment.

The important role of the paradigm of constructivism for the functioning of the digital educational environment is pointed out by Tchoshanov [52]. Lee and Lin [53] demonstrate the paradigm application in the context of distance and blended learning emphasizing that the aim of any methodological system is not transfer of knowledge in a ready form but creation of pedagogical conditions for successful self-development of learners according to their own educational trajectory. In addition, the paradigm of constructivism is characterized by personal orientation and respect for students, promoting independence, teamwork, attention to the formation and development of skills to solve problems of different sources [54], i.e. flexible skills or skills of the 21st century.

Note that STEM education, as well as the method of M. Montessori, in addition to scientific and technological components of education, focused on creative development of personality, critical thinking, independence in decision-making, empathy for society and other characteristics that are key skills of the 21st century.

Another important feature characteristic of the STEM / STREAM approach in teaching and methods of M. Montessori is the use of toys (from simple to technically and technologically oriented) and game techniques to acquire new knowledge and skills [11]. They teach to master the laws of nature, the idea of how our world works and how to explore the surrounding space, first of all, by improvised means. In general, the gamification of the educational process is one of the driving forces of these learning technologies [55, 56, 57, 58, 59, 60].

4.2. Analysis of web mapping data about Montessori centers in Ukraine

The compliance of educational service centers was checked by researching the content of the Institutions site. Based on a detailed analysis of all the results provided by the system for each of the inquiries and the separation of those that do not use the principles of the pedagogical system of M. Montessori, a map showing all institutions of formal and non-formal education of public and private property that fully or partially declare the use of these principles of learning was drawn up (figure 2).

As can be seen in figure 2, the largest number of Montessori centers operating in Ukraine is concentrated in the capital and western regions (Lviv and Volyn), the smallest part is determined in the eastern regions of the country. The study showed that there are 60 centers in the central regions, 24 in the eastern regions, 75 in the western regions, 45 in the northern regions, and 47 in the southern regions. The significant number of Montessori centers in Kharkiv (14) and Cherkasy (12) regions is obviously due to the presence of powerful centers in these regions such as pedagogical universities. This method is the least popular in Luhansk, Zakarpattia and Khmelnytsky regions.

In order to identify the features of modern educational environments of M. Montessori schools, we analyzed the online content of the proposals of such educational centers, which are highly valued by network users (one example from the relevant region of Ukraine). Let us briefly consider the educational

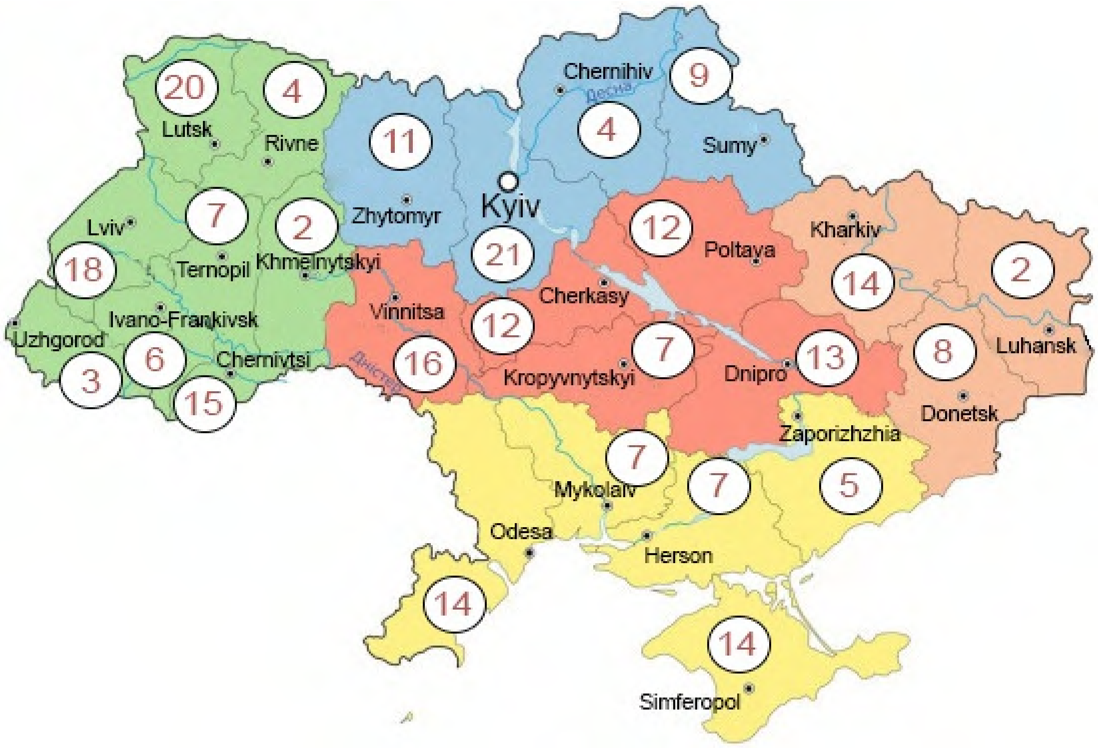

Figure 2: Distribution of Montessori pedagogy centers in Ukraine.

proposals of some of them. Thus, the Center for Child Development mini-kindergarten "Lviv Montessori School" implements a program for children 6–12 years old and is a full-time educational institution where, in addition to standard subjects, children study supplementary subjects: physics, chemistry, worldview, art of photography, painting, choreography, piano, and have thematic excursions [61]. An important feature of the pedagogical methodology of this school, as stated on the website of this educational institution, is the use of active self-assessment by pupils, cooperation (children of different ages spend a significant amount of time together, they have to work together to solve different problems). Based on this, pupils do not get ready for the sake of assessments, but because they are interested in learning and exploring the world around them.

Another example of effective implementation of Montessori's ideas in practice is the program of the Center for Child Development "Anthill" in Ternopil, which combines traditional forms and methods of working with younger pupils and the so-called "events" in a prepared environment where pupils can choose activities, interact with children of other ages, independently study the objects of this environment [62].

Montessori New Age School has a "Montessori class", which is equipped with a complete set of Montessori materials for comprehensive and harmonious development of children and is divided, like the STEM learning space, into several functional areas; some of them are designed to develop a variety of practical skills, improve motor skills and coordination. Also, there are materials for the development of sensory sensations, speech, mathematical abilities, as well as acquaintance with the world around [63]. It is also emphasized the importance of the role of the teacher: "conducts constant observation and ... knows at what stage of development each child is, what occupation should be offered to him for a further step forward". Attention is drawn to the significance of the mixed-age groups of Montessori New Age School, which creates optimal conditions for the social upbringing of children on the principle of a large family and folk pedagogy. The mission of the New Age School is to create a special educational environment in which children learn through their own experiences and feelings.

The study showed that the activities of Montessori pedagogy centers in Ukraine are mainly focused on the education and training of preschool children. Some example is the Montessori World full cycle school in Kharkiv [64], which uses an interdisciplinary approach to designing courses and curriculum subjects with a special emphasis on preparing children through practical activities for real life. Among the training courses are the following: writing and project activities (for example, spelling is studied on topics that interest children: human structure, animal habitat, rivers or volcanoes of different continents); publication of a school newspaper studies to keep the audience's attention, present the project, ask questions, gain experience in public speaking. Due to special manuals and didactic materials, children can divide the whole into parts, solve geometric problems and prove theorems. The course "Physics, Chemistry, Astronomy" is aimed primarily at experimental activities, creating projects that are the foundation for in-depth study of these sciences at high school, the course "History and Geography" uses elements of museum pedagogy. Communicating with teachers of Karazin University in classes on "Botany and Zoology", children observe plants and insects, care for animals in their own "living space" and grow plants. During classes "Financial knowledge and management" pupils learn to put financial and economic aims, manage finances and plan a budget, in particular, through outings, excursions, teamwork at fairs, holidays, purchasing products. The course "Art and Painting" includes regular master classes on felting wool, origami, etc. Besides, it is aimed at developing practical life skills and social responsibility: children develop menus, prepare dinners, set the table, wash dishes, clean the classrooms, clean up the forest of rubbish, sort garbage, and hand over waste paper. In this Montessori environment, pupils participate individually and in groups. Classes are divided into thematic areas: mathematics, languages, geography, history, biology, space; there is a laboratory. Due to this the learning approach is realized: teach the child to think, find solutions, make discoveries, search for information and be able to apply it when needed.

It should be noted that most educational institutions that use Montessori's ideas are private, such as the Clever Kids Elementary School in Kyiv. In addition to the annual curriculum in accordance with the standard, for each child, taking into account the gifts and flaws of the pupil, his abilities, main interests, age goals, phase of character development, and level of ability to control emotions and interact with the team is worked out a personalized curriculum [65]. Particular attention is paid to the formation of project activities skills that promote children's interest in research, skills of planning and organizing their working time, critical, analytical and abstract thinking skills, and teamwork. Among the pedagogical tasks of the Clever Kids are also assistance in the pupil potential development, development of independence and self-sufficiency of thinking, respect and empathy for others, responsibility and leadership qualities. There are created conditions for the development of children based on their individual step and biological rhythm, formation of skills of independent work, promoting the initiative in the choice of materials, stimulating the development of self-discipline skills, cooperation with parents and more. Emphasis is placed on the importance of the activities of teachers, whose mission is to find ways to inspire children to learn. Such support allows children, first of all, to gain confidence and strive to perform tasks constantly without fear of failure. Emphasis is placed on the gradual complication of tasks, which creates opportunities to go through the process of aim setting and experience of personal victory.

Thus, the study of information about Montessori education centers in Ukraine showed that the modern interpretation of pedagogical postulates for socialization and upbringing of the child is indisputable and can resolve the contradictions associated with the implementation in practice of the basic requirements for the modern educational process: individualization, reliance on sensitive periods, the priority of personal independence, the ability to make choices and respect the choices of others, freedom and discipline in different age communication, etc.

Our study showed that there are more than 250 educational institutions in Ukraine that use the methods and principles of teaching Maria Montessori. For comparison, in Germany there are about 1000 preschool institutions and 400 schools operating on the basis of Montessori pedagogy: gymnasiums are 40 percent, general schools – 25%, primary – 20% and real schools – 15% [66]. Thus, the ideas and pedagogical system of M. Montessori remain relevant in the education of the 21st century.

4.3. Analysis of web mapping data about STEM-STEAM-STREAM centers in Ukraine

For comparison, a map of the development of STEM-STEAM-STREAM centers was created in a similar way (figure 3).

Figure 3: STEM-STEAM-STREAM centers in Ukraine.

Our research showed that there are more than 190 teaching centers in Ukraine that use STEM-STEAM-STREAM technologies. 45 STEM centers are functioning in the central regions, 9 centers in the east regions, 62 centers in the western regions, 41 centers in the northern regions, 30 centers in the southern regions. This is due to the fact that STEM education in Ukraine is only gaining popularity, and their largest number we have only in large cities (Kiev, Lviv). The smallest number of STEM institutions is located in the eastern and southwestern regions.

The obtained data on the development of educational centers in Ukraine based on the pedagogy of M. Montessori and STEM-STEAM-STREAM centers are presented in the form of diagrams (figures 4, 5).

The development of Montessori pedagogy, which is presented on figure 4, shows that the Montessori concept is widely known in Ukraine. Nonetheless, since this practice is used only by private schools and kindergartens, it is not available for many children and its percentage is small in some regions. The largest centers and networks of STEM centers and Montessori schools are located in Kyiv.

5. Conclusions

We have analyzed the similarities and differences between M. Montessori methodology and STEM approach in education, both based on the constructivist philosophy in education. We have demonstrated the relevance and complementarity of these ways in formal and non-formal education in Ukraine by using web mapping service Google Maps to visualize the distribution and growth of Montessori and STEM educational centers. We have argued that the organizational and pedagogical condition for their effective integration is the creation of a special learning environment that can adapt to the personal ideals and cognitive needs of the learners, as well as foster the development of soft skills [67, 68].

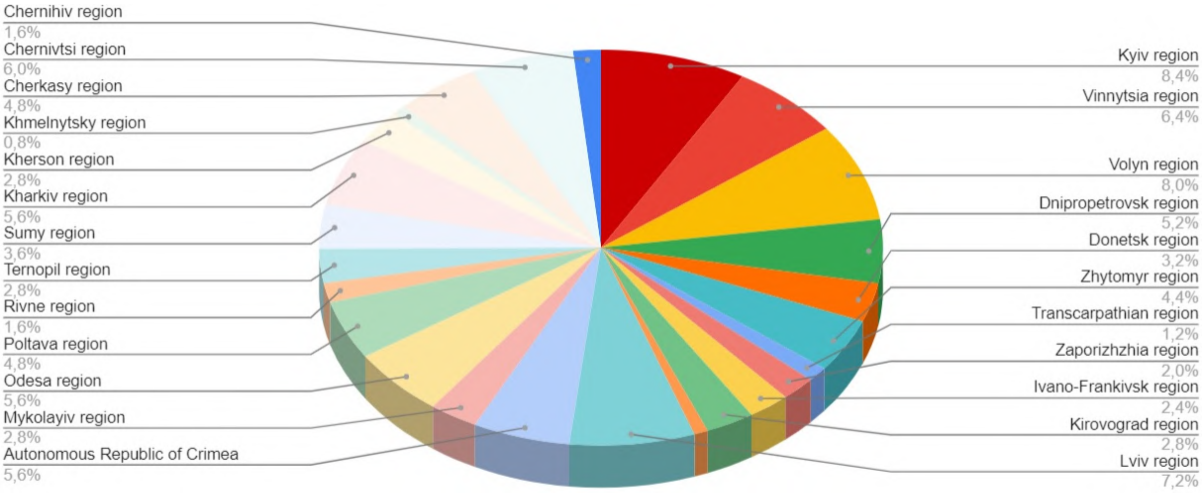

Figure 4: Quantitative distribution of Montessori pedagogy centers in Ukraine.

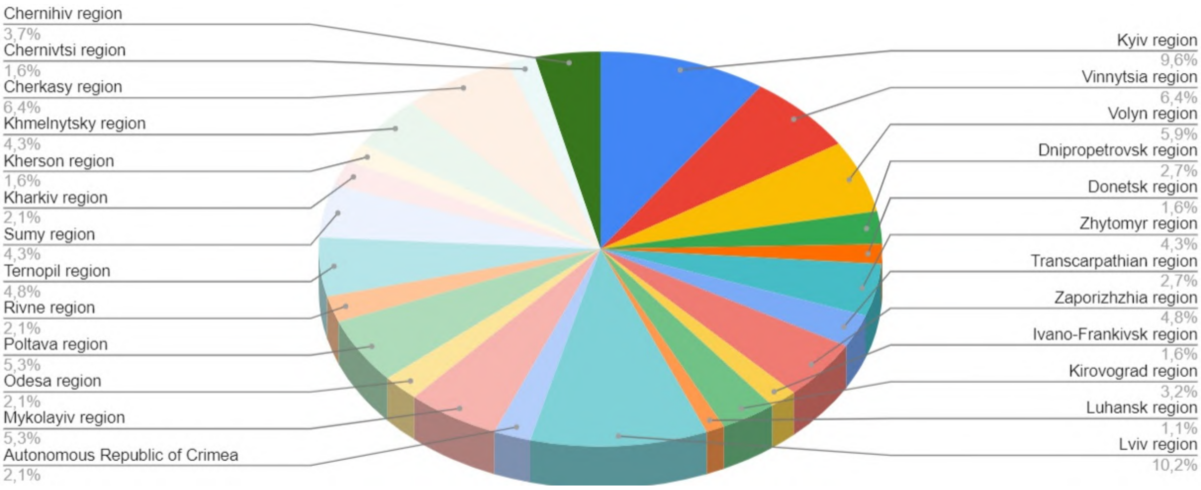

Figure 5: Quantitative distribution of STEM-STEAM-STREAM centers in Ukraine.

We have also identified some common didactic features of Montessori and STEM technologies, such as:

- the emphasis on the formation of a lasting interest in the processes and phenomena in the world, the development of curiosity based on research using the steps of the scientific method and the engineering design process;
- the transformation of the role of the teacher, from a transmitter of knowledge to a facilitator of learning, a motivator of productive activities, a stimulator of development, and a creator of a pedagogical ecosystem that fosters the formation of a scientific worldview and the key skills of the 21st century in the students.

By comparing the maps created by Google Maps, we have concluded that the Montessori methodological system has adapted to the rapid development of technology and machinery in the 21st century; the popularity of STEM educational centers is increasing rapidly in Ukraine (almost 200 new centers in 10 years). We have used the Gartner Hype Cycle method to describe this process [69] and suggested that Montessori pedagogy is now on a "plateau of productivity" and that STEM approaches in education are in a state of active implementation, which corresponds to "innovation trigger" and approaches the "peak of inflated expectations".

We have proposed that STEM technologies of teaching and pedagogical ideas of M. Montessori can harmoniously complement each other, especially in the context of forming the ability to successful self-development based on maintaining the relationship between the child and the developmental subject-spatial environment (M. Montessori), which can be digital (STEM) in the present time.

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Prospects of quantum informatics and studying its basics in school courses

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Abstract

The purpose of this study is to review the main points of the experimental content of the basics of quantum computer science adapted for lyceum students, based on the prospects of the quantum approach to information processing for ultra-fast calculations in modeling objects of complex dynamical systems. In addition, software tools and Internet services are offered to organize effective training. A survey was conducted among 26 computer science teachers to assess the relevance and feasibility of introducing a "Fundamentals of quantum informatics and programming" course for lyceum students. The proposed 17-hour sample module covers key concepts of quantum computing, quantum circuits, quantum gates, and basic quantum algorithms. Expected learning outcomes and methodological support are discussed. The study concludes that quantum computer science has significant potential and proposes starting to study its basics in the school computer science course in grades 10-11, using universal software and Internet services like IBM Quantum Experience and Jupyter Notebooks with Python.

Keywords

quantum computing, quantum computer, quantum circuit, quantum algorithm, IBM Quantum Experience, Python, Jupyter Notebook

1. Introduction

According to experts, the modern IT market is in the initial state of another technological breakthrough due to integration (interpenetration, convergence) of 1) nanotechnologies (the ability to control matter at the atomic level), 2) biotechnologies (the ability to manipulate genes and genetic information), 3) information technologies (the use of communication and communication tools) and 4) cognitive technologies (the study of the fundamental essence of thought processes and their mechanisms) [1].

The capabilities of modern supercomputers ("computers of classical architecture", "classical computer") are no longer enough for efficient processing of large amounts of data during modeling of nanoobjects, biogenetic systems, cognitive processes, and other phenomena. It is felt that the development of transistor computers has almost reached its limit and that Moore's Law, which consists in doubling the computer power every one and a half to two years, will soon cease to hold since the size of transistors will stop decreasing every 18 months [2, 3, 4]. A quantum approach has a significant potential for data processing (information), for increasing the productivity of cumbersome and secure calculations, for reliable storage of their results in scientific fields, in logistics, safe trade, and finance, i.e. new computer science – quantum information science, or quantum informatics.

2. Background

2.1. Quantum informatics

Quantum informatics (as a new branch of science, the subject of which is the theory and practice of using quantum objects for transmission and procession of quantum information), in addition to quantum

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information theory and quantum algorithms, includes physics and mathematics of quantum computers, problems of decoherence description, measurement problems, issues of quantum cryptography, simulation modeling of quantum systems, quantum intelligence, etc. [5]

2.2. Need for quantum education

Leading IT companies, in particular, IBM (since 2016), Intel (since 2017), and Microsoft offer free access to experimental models of next-generation computers as an Internet service to all interested parties [6, 7, 8]. However, school computer science course, which is updated every 3–5 years, does not address at all either the general principles of functioning of quantum computers and the peculiarities of their management or the fundamental principles of quantum computer science.

Taking into account the prospects of quantum modeling of complex systems of various nature, particularly cryptographic, chemical, and economic [9, 10, 11], we consider it appropriate and possible to generalize, systematize, and adapt the basics of quantum informatics for mastering it by lyceum students.

3. Methodology

For effective studying of the training material, students are offered to work with universal and special software and Internet-services:

1) for building the quantum circuit using drag-and-drop technology in remote mode – Circuit Composer from IBM Quantum Experience Lab (figure 1, [6]);
2) to master the mathematical foundations of quantum calculations and the implementation of basic quantum algorithms in the local mode of Anaconda Navigator environment – the manager of packages and programming environments (figure 2);
3) for studying the mathematical foundations of quantum calculations and the implementation of basic quantum algorithms remotely using Collaborative Calculation and Data Science (CoCalc).

CoCalc (figure 3, [12, 13, 14]) is an entire computer lab in the cloud where:

- each student works 100% online – in their own, isolated workspace;
- you can follow the progress of each student in real-time;
- at any time you can jump into a file of a student, right where they are working;
- you can use TimeTravel to see each step a student took to get a solution;
- integrated chat rooms allow you to guide students directly where they work or discuss collected files with your teaching assistants;
- the project's activity log records exactly when and by whom a file was accessed.

The author's team is developing a set of educational and methodical materials, which includes:

- educational and methodical manual;
- collection of educational presentations;
- collection of educational video podcasts;
- electronic workbook;
- bank of test tasks.

After finishing the development of a set of educational materials adapted for students, it will be possible to move on to a large-scale experiment on studying the basics of quantum informatics and programming by the lyceum students.

A survey was conducted among computer science teachers of general secondary education institutions to study the expediency and readiness of teachers to teach the course "Fundamentals of quantum informatics and programming" for lyceum students. 26 teachers of Computer Science, Chemistry,

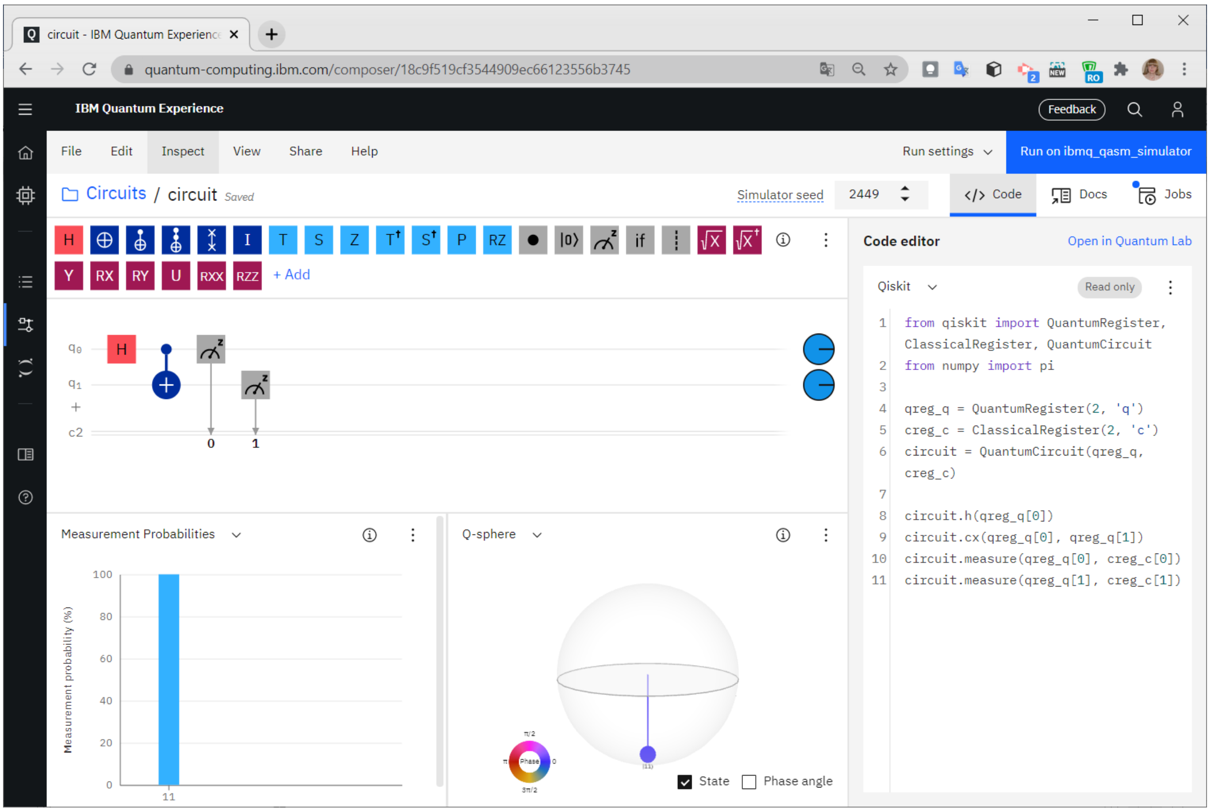

Figure 1: Page with quantum circuit composer from IBM Quantum Experience.

Technology, and Mathematics took part in the survey, the vast majority of them live in a city of regional subordination. The age of teachers who answered the questions was as follows: 7.7% – 25–35 years; 30.8% – 25–35 years, 42.3% – 35–45 years, 15% – 45–55 years; 3.8% – over 55 years.

100% of respondents supported the statement that secondary education should provide up-to-date knowledge and take into account modern achievements of the industry when studying the discipline. All respondents indicated that they use cloud technologies when teaching their subject (65.4% – always, 34.6% – during distance learning). Only one survey participant disagreed with the fact that the training material can and should be adapted according to age.

96.2% of teachers indicated that they are happy to accept the introduction of new sections and topics in the curriculum of the discipline, especially if there is sufficient and high-quality methodological support.

Responses from respondent teachers indicate that 88.5% of those who took part in the survey expressed the opinion that they would like to personally take the course “Fundamentals of quantum informatics and programming”, and 38.5% of them said that they had met many publications on this topic and were interested. 61.6% of teachers said that you would offer a course “Fundamentals of quantum informatics and programming” for applicants for education in your institution. 23.1% refused because, in their opinion, this course would not correspond to the profile of the educational institution where they work. Only 3.8% answered “no”.

4. Proposed course content

The study of the basics of quantum informatics and programming is proposed to be organized either within the framework of a new (experimental) sample module of the same name – “Fundamentals of quantum informatics and programming” – a standard-level program for pupils of 10-11th grades, or, in an extended version, within the framework of the same elective course, the amount of study hours is 17 and 35, respectively.

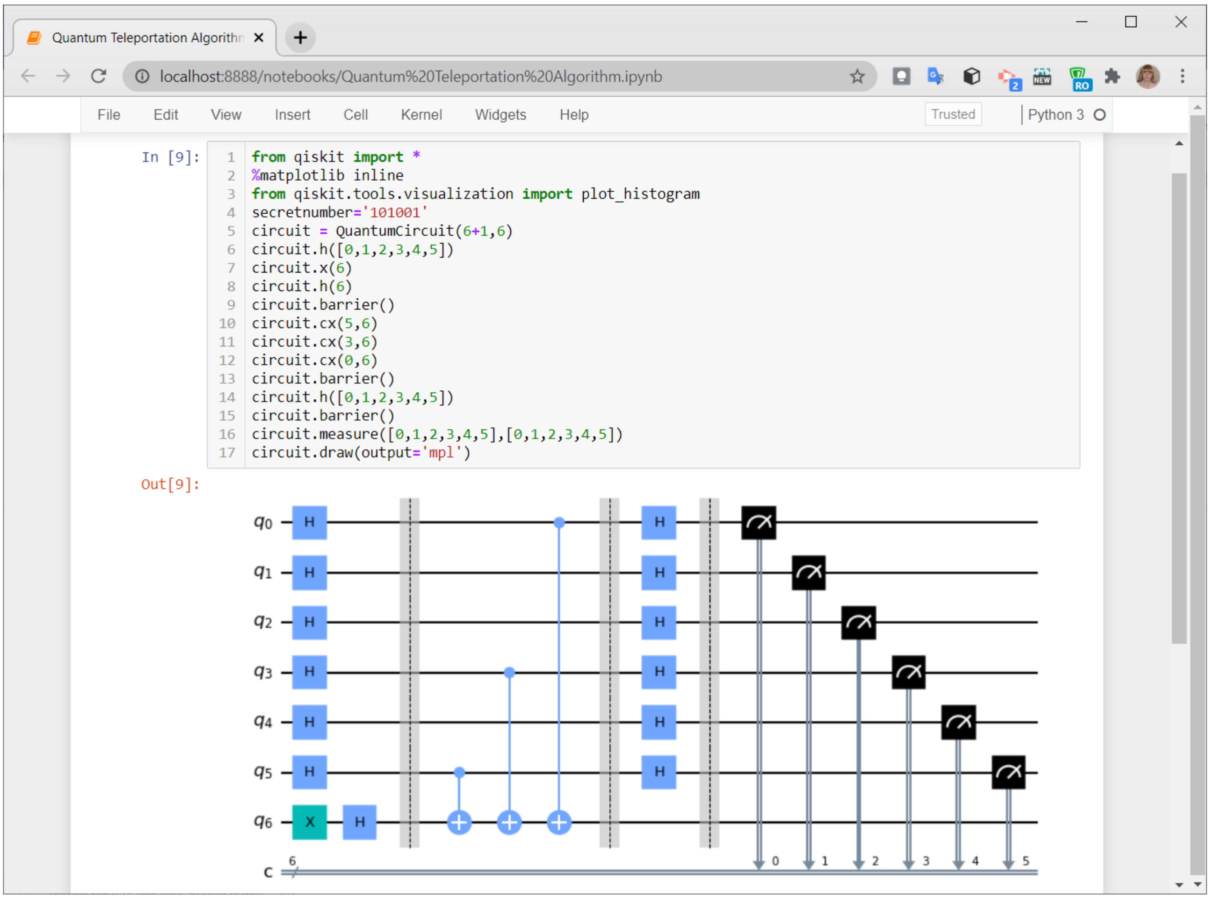

Figure 2: Jupyter notebook page in local access.

The purpose of teaching the sample module (elective course) “Fundamentals of quantum informatics and programming” (table 1) there should be the development of the components of computer literacy and information culture of lyceum students through the acquisition of basic theoretical knowledge and practical skills to manage quantum computers as new generation computers.

To achieve this goal (according to the content presented in table 1), it is planned to solve the following tasks:

- to form the concepts of “quantum computer”, “qubit”, “quantum superposition”, “quantum logic gate”, “quantum algorithm”, “quantum circuit”, “quantum entanglement”, “quantum programming language”, etc.;
- to acquaint with the history of formation, the current state, and development prospects of quantum informatics;
- to introduce physical and mathematical foundations of quantum computing;
- to study the potential and determine the advantages of quantum computers for solving individual applied problems, modeling problems of complex systems of various nature, etc.;
- teach the pupils to implement basic quantum algorithms in special and universal environments with remote and local access.

The expected results of mastering the educational material of the first three lessons – “Digital technologies: history of formation, current state, development prospects”, “Basics of classical computer arithmetic”, and “Basics of classical computer logic” are as follows:

- student explains the concepts of digital technologies, classical computers, processor and memory of a classic computer; number system, number system alphabet, basis of the positional number

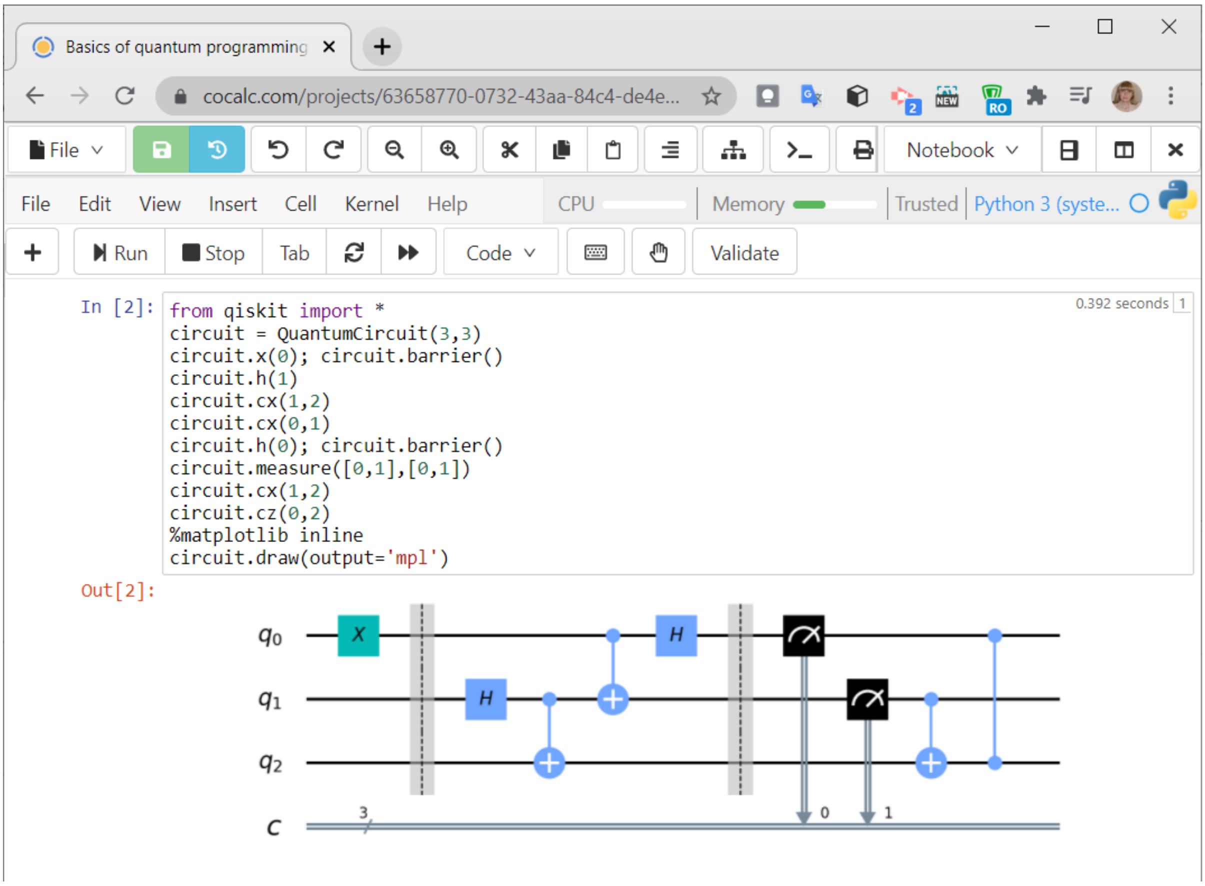

Figure 3: Jupyter notebook page in the CoCalc cloud environment.

system; binary message code, length of binary message code, units of measurement for the length of binary message code;
- student knows the quantum computer definition, general principles of its structure and functioning, and the peculiarities of its using;
- student understands the typical architecture of a classic computer and the general principles of its operation;
- student names the units of measurement of the length of the binary message code (bits, bytes, kilobytes, megabytes, gigabytes, terabytes);
- student describes the general principles of operation of the processor and internal storage devices;
- student is able to convert natural numbers from decimal to binary and vice versa; determine the length of the binary message code; arithmetic addition and multiplication of binary numbers; logical operations not, and, or, xor over binary numbers;
- student is aware of the role of existing (classical) digital technologies and the significance of their development prospects.

5. Conclusions

1. The new branch of computer science – quantum computer science – has significant potential for increasing the productivity of cumbersome and secure computing, for reliable storage of their results in scientific fields, in the spheres of logistics, safe trade, and finance.
2. It is proposed to start studying the basics quantum computer science and programming in the school computer science course (obligatory-selective for students of grades 10-11) within the framework of a new (experimental) module (17 hours) according to the lyceum curriculum of the standard level or an elective course (35 hours) of the profile level curriculum.

Table 1
"Fundamentals of quantum informatics and programming": draft content of the sample module (17 hours)

N	Topics
1	Digital technologies: history of formation, current state, prospects of development
2	Basics of classical computer arithmetic
3	Basics of classical computer logic
4	Complex numbers fundamentals
5	Working with linear algebra objects: vectors
6	Working with linear algebra objects: matrices
7	Key concepts of quantum computing
8	Quantum circuits and their design environments
9	Quantum NOT gate
10	Hadamard quantum gate
11	Quantum CNOT gate
12	Quantum Toffoli and Fredkin gates
13	Basic quantum algorithms and peculiarities of their implementation using a programming language
14	Quantum teleportation algorithm
15	Deutsch–Jozsa algorithm
16	Shor's algorithm
17	Grover's algorithm

3. For effective studying of the training material, students are offered to work with universal and special software and Internet-services – IBM Quantum Experience, Jupyter Notebook using Python programming language (in remote or local access).

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Enhancing mathematical understanding through dynamic GeoGebra modeling: A holistic educational approach

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Abstract

This paper presents an innovative approach to enhancing mathematical understanding through interactive modeling using GeoGebra software, based on holistic educational principles. The research describes the development and implementation of a comprehensive complex of dynamic mathematical models created within inter-university projects of the Kharkiv GeoGebra Institute. The complex comprises three distinct categories of models: fundamental mathematical concept visualization, transdisciplinary connections demonstration, and real-world problem-solving applications. A systematic methodology for model development was implemented, incorporating theoretical foundations of holistic education and practical considerations for effective visualization. The paper details the technical implementation using GeoGebra tools, discusses specific examples of models created, and presents the pedagogical framework for their application. Special attention is given to the development of supporting didactic materials that guide learners through active investigation using the dynamic models. The research demonstrates how this approach facilitates deeper mathematical understanding by connecting abstract concepts with practical applications and fostering active learning through visualization and experimentation. Results indicate that the developed complex of models effectively supports the implementation of holistic educational principles in mathematics education, particularly in establishing meaningful connections between mathematical concepts and their real-world applications.

Keywords

dynamic mathematics software, interactive modeling, mathematical visualization, GeoGebra, transdisciplinary connections, holistic mathematics education

1. Introduction

Contemporary mathematics education faces significant challenges in fostering deep understanding and meaningful engagement among students. Recent studies by Vlasenko et al. [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11], Lovianova et al. [12, 13], Kramarenko et al. [14], Kramarenko and Kochina [15], Ponomareva [16], Merzlykin et al. [17], Tarasenkova et al. [18], Achkan et al. [19] highlight persistent gaps in mathematics education at both secondary and university levels. These challenges manifest in students' difficulties with abstract concepts and their practical applications, ultimately affecting their overall mathematical competence.

The core issues in mathematical education, as identified by Bilousova et al. [20] and diSessa et al. [21], include:

- Students' struggle with abstract mathematical concept comprehension
- Limited ability to apply mathematical knowledge to practical tasks
- Diminishing interest in mathematics due to perceived complexity
- Failure to recognize mathematics' role in other disciplines

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A fundamental challenge lies in students' lack of holistic understanding of mathematics as both a theoretical framework and a practical tool for solving interdisciplinary problems. As Singh [22] emphasizes, this disconnect between abstract mathematical concepts and their real-world applications often results in decreased motivation and engagement.

The holistic educational paradigm offers a promising approach to address these challenges. According to Miller [23, 24], holistic education emphasizes:

1. Learner autonomy and active participation
2. Integration of knowledge across disciplines
3. Connection between academic concepts and real-world experiences
4. Development of comprehensive understanding through practical application

Computer Dynamic Models (CDM) emerge as powerful tools for implementing holistic education principles in mathematics teaching. Research by Semenikhina and Drushliak [25] and Alessi [26] demonstrates that CDMs can effectively:

- Visualize mathematical concepts in real-time
- Enable active exploration of mathematical relationships
- Facilitate understanding of transdisciplinary connections
- Support development of integrated thinking skills

Among available mathematical software, GeoGebra stands out for its comprehensive modeling capabilities. Study by Kramarenko et al. [27] highlight GeoGebra's effectiveness in creating interactive visualizations and supporting mathematical investigation. The software enables seamless integration of geometric and algebraic representations, facilitating dynamic visualization and manipulation of mathematical concepts [28].

The Kharkiv GeoGebra Institute, operating within the International GeoGebra Institute network since 2010, focuses on:

1. Promoting effective implementation of GeoGebra in mathematical education
2. Supporting research in mathematics, physics, and computer science
3. Advancing STEM education through technology integration
4. Fostering international collaboration in mathematical education

This paper presents the results of an inter-university project conducted through the Kharkiv GeoGebra Institute, focusing on developing a comprehensive complex of dynamic models for holistic mathematics learning at the university level.

2. Theoretical framework

The development of our GeoGebra model complex is grounded in both theoretical principles and practical considerations, implemented through a systematic methodology combining theoretical, empirical, and modeling approaches.

2.1. Methodological foundation

The project's initial phase established three fundamental requirements for the model complex:

1. Development of diverse model categories:
    - Basic mathematical concept visualization
    - Transdisciplinary connection demonstration
    - Real-world problem-solving applications
2. Implementation of dynamic, interactive elements to support active learning

3. Cloud-based accessibility through www.geogebra.org

Following Bevz [29] and diSessa et al. [21], we approached transdisciplinary connections through three primary dimensions:

- Content integration across disciplines
- Learning activity structure
- Educational process organization

2.2. Theoretical analysis process

The analytical phase involved comprehensive examination of:

1. Core mathematical concepts and their interdisciplinary applications
2. Curriculum content threads [30, 31]
3. Transdisciplinary connection patterns

This analysis revealed key connection chains between mathematics and other disciplines:

- Mathematics – Computer Science
- Mathematics – Physics
- Physics – Mathematics – Biology
- Mathematics – Economics
- Mathematics – Engineering Design

The theoretical framework was further enhanced through semantic analysis using specialized software tools, including TextAnalyst 2.0, Text Miner 12.1, and Trope 8.4, enabling identification of key learning elements and their interconnections across disciplines.

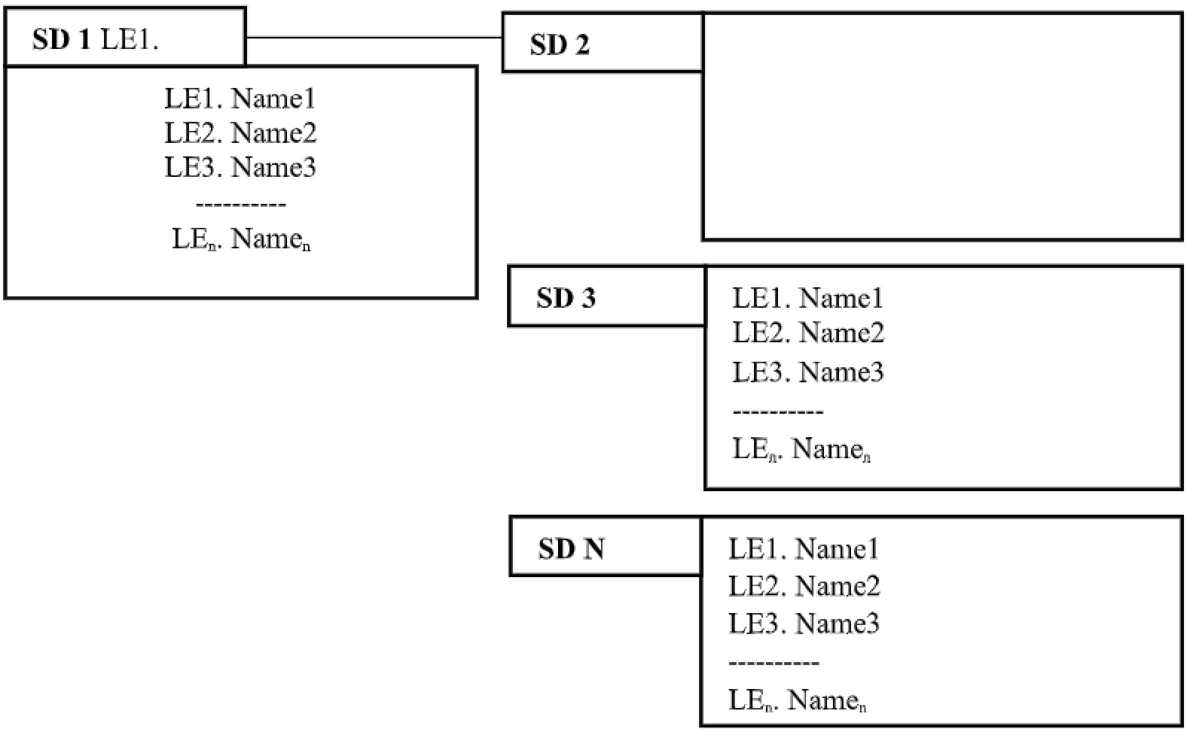

Figure 1: The common scheme of the graph, representing their transdisciplinary links with exact learning elements (LE1...LEn) of subject domains (SD).

This theoretical foundation guided the subsequent development of practical models and their implementation in educational settings. The framework emphasizes the importance of active learning, visualization, and practical application in mathematical education, aligning with holistic education principles outlined by Miller et al. [32] and Mahmoudi et al. [33].

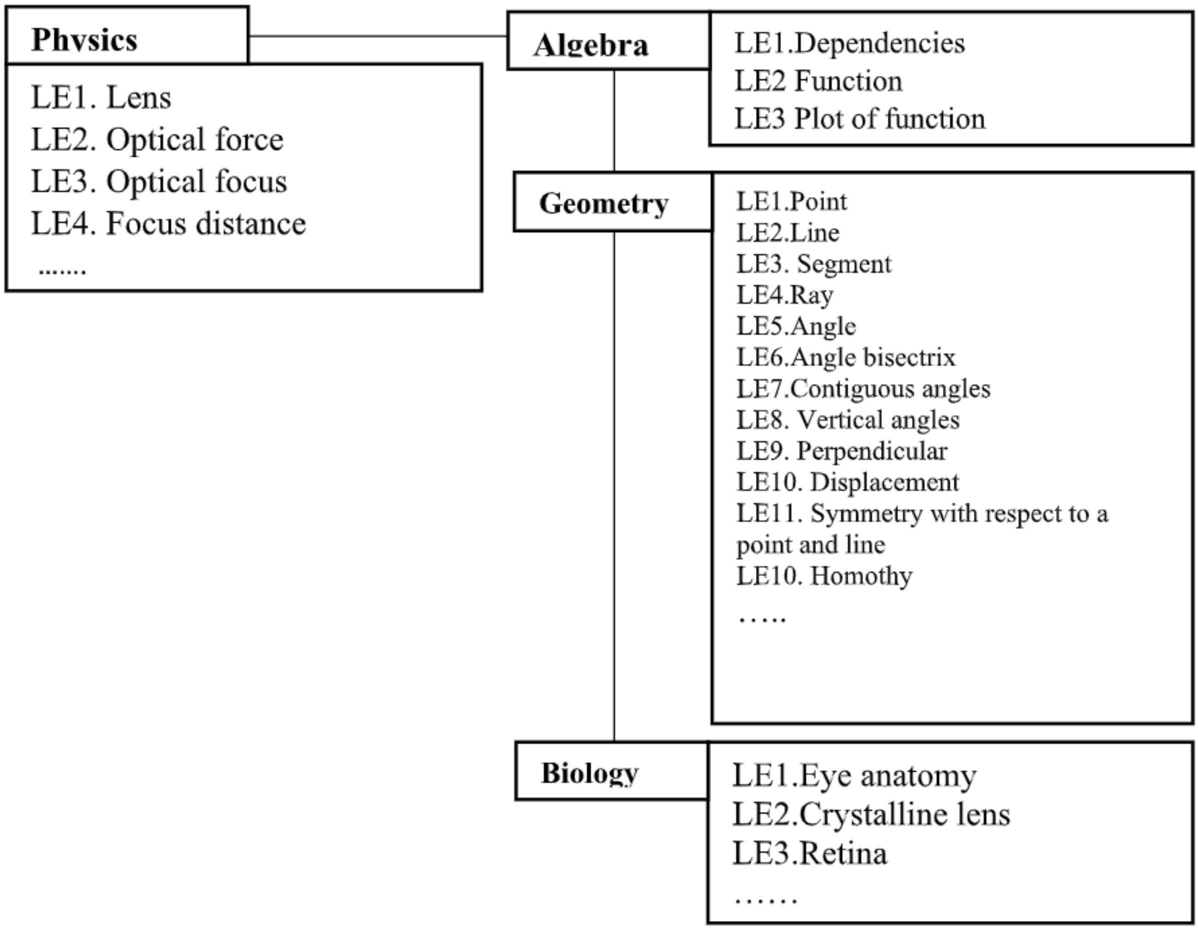

Figure 2: The example of the graph for selected LEs, representing the transdisciplinary links for the chain: Physics – Mathematics – Biology (Used below for the transdisciplinary model "Lens").

3. Results and discussion

3.1. Model development process

The implementation of the theoretical framework resulted in a systematic model development process comprising several key phases:

3.1.1. Phase 1: Mathematical model construction

For each model, the development process included:

1. Analysis of transdisciplinary concept relationships
2. Definition of mathematical dependencies for visualization
3. Specification of model parameters (fixed and variable)
4. Selection of appropriate graphical elements
5. Identification of relevant applications and problems
6. Development of supporting didactic materials

3.1.2. Phase 2: GeoGebra implementation

The technical implementation utilized various GeoGebra tools [25, 28]:

- Standard geometric tools (Points, Lines, Polygons)
- Computer Algebra System (CAS) components

- Dynamic transformation tools
- Action Object and Movement tools

3.1.3. Phase 3: Testing and refinement

The models underwent rigorous testing and improvement cycles to ensure educational effectiveness and technical reliability.

3.2. Model categories and examples

3.2.1. Category 1: Basic mathematical concepts

These models focus on fundamental concept visualization and understanding. Notable examples include:

Example: Remarkable curves investigation – epicycloids
Chain of transdisciplinary links: Geometry – Algebra – Mechanics
The model demonstrates epicycloid construction and properties, enabling investigation of:

- Relationship between curve lobes and radius ratios
- Position calculations using geometric parameters
- Transformation between epicycloids and hypocycloids

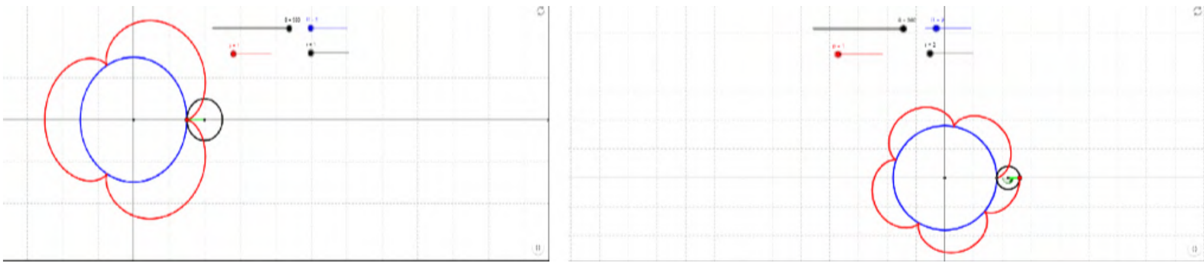

Figure 3: Episodes of the students'cognitive activity with the dynamic model “Remarkable curves investigation – epicycloids”.

3.2.2. Category 2: Transdisciplinary connections

These models emphasize interdisciplinary relationships, as demonstrated in the following example:

Example: Lens Model
Chain of transdisciplinary links: Physics – Mathematics – Biology
The model illustrates optical principles through mathematical relationships:

- Lens curvature effects on focal points
- Mathematical relationships in image formation
- Geometric properties of light paths

Supporting tasks include:

1. Investigation of mathematical dependencies
2. Analysis of geometric properties
3. Integration with biological systems (human eye)

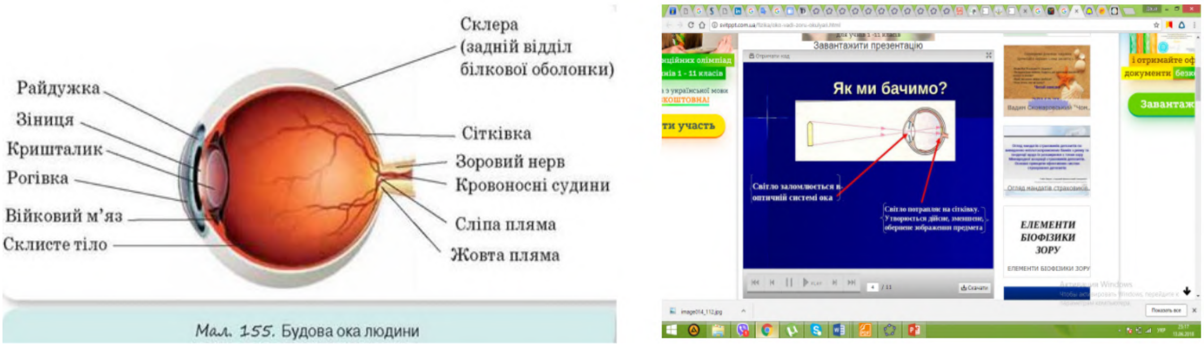

Figure 4: Scheme of the optical system of a human eye.

3.2.3. Category 3: Real-world applications

This category focuses on practical problem-solving, exemplified by:

> **Example: Fermat-Torricelli points investigation**
> The model supports various real-world investigations:
> 1. Construction and property analysis
> 2. Application to urban planning
> 3. Resource optimization problems

3.3. Educational impact and implementation

The implementation of these models demonstrates several key advantages:

1. Enhanced visualization: following principles outlined by Kramarenko et al. [34], the models provide dynamic visualization of abstract concepts.
2. Active learning: as suggested by Tarasenko et al. [35], interactive elements encourage student engagement and exploration.
3. Practical application: the models bridge theoretical understanding and practical implementation, supporting findings by Bilousova et al. [20].
4. Cloud integration: cloud-based accessibility aligns with modern educational needs [36, 37].

3.4. Didactic support framework

The developed didactic support materials include:

1. Transdisciplinary connection tasks
   - Concept relationship identification
   - Cross-disciplinary application exercises
   - Integration-focused problems
2. Practical application tasks
   - Real-world problem solving
   - Industry-specific applications
   - Contextual learning activities
3. Investigation guidelines
   - Step-by-step exploration procedures
   - Parameter manipulation instructions
   - Analysis and conclusion frameworks

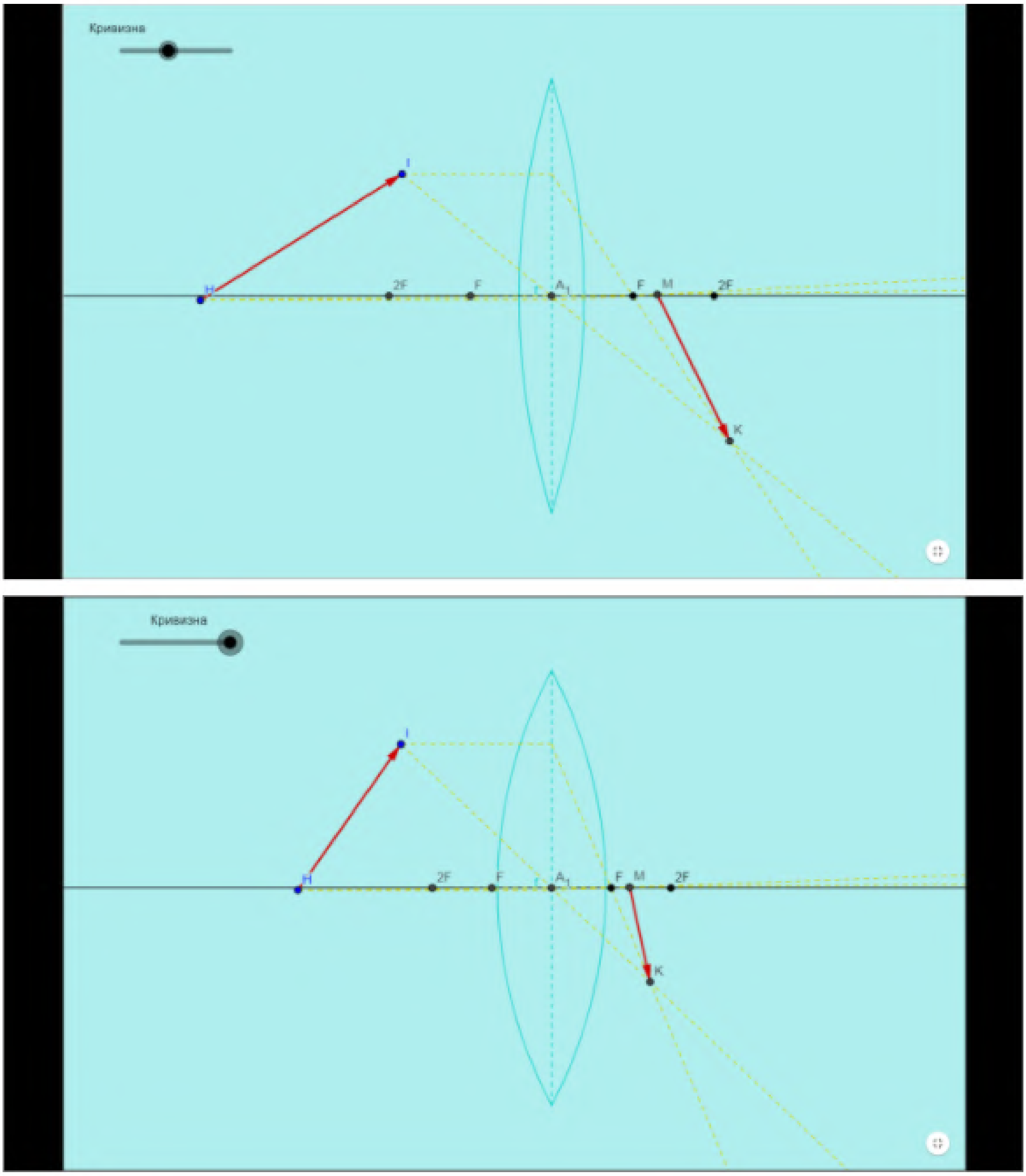

Figure 5: Episodes of transdisciplinary tasks solving, operating the model “Lens”.

3.5. Future research directions

Based on our findings, several promising research directions emerge:

- Long-term impact assessment on student understanding
- Development of additional model categories
- Integration with emerging educational technologies
- Extension to other STEM disciplines

4. Conclusions

This research demonstrates the successful development and implementation of a comprehensive GeoGebra-based modeling complex for enhancing mathematical education through a holistic approach. The key findings and contributions can be summarized in several dimensions:

4.1. Model development framework

The research established a systematic approach to creating educational mathematical models, incorporating:

- Robust theoretical foundations drawing from holistic education principles
- Structured development methodology across three distinct model categories
- Integration of dynamic visualization with practical applications
- Cloud-based deployment for widespread accessibility

4.2. Educational innovation

The developed complex advances mathematical education through:

1. Enhanced visualization: synamic models provide immediate feedback and interactive exploration opportunities, supporting findings by Kramarenko et al. [27] regarding the effectiveness of visual learning in mathematics.
2. Transdisciplinary integration: following principles outlined by Gryzun [38], the models successfully bridge multiple disciplines, demonstrating mathematics' role in various fields.
3. Active learning support: interactive elements encourage student engagement and independent exploration, aligning with Bilousova et al. [20]'s recommendations for effective mathematics education.
4. Practical application: teal-world problem-solving capabilities address the gap between theoretical understanding and practical implementation identified by diSessa et al. [21].

4.3. Technological implementation

The research demonstrates successful utilization of GeoGebra's capabilities through:

- Effective integration of geometric and algebraic representations
- Development of interactive, user-friendly interfaces
- Implementation of cloud-based accessibility
- Creation of scalable and modifiable models

4.4. Pedagogical implications

The research yields significant implications for mathematics education:

1. Enhanced teaching methodology: the model complex provides educators with tools for implementing holistic teaching approaches, supporting findings by Miller [24] regarding effective mathematical instruction.
2. Student engagement: interactive elements and real-world applications increase student motivation and understanding, addressing challenges identified by Singh [22].
3. Flexible learning support: cloud-based accessibility enables both classroom and independent learning, aligning with modern educational needs [39].
4. Comprehensive understanding: the transdisciplinary approach fosters deeper mathematical comprehension, supporting principles outlined by Mahmoudi et al. [33].

4.5. Future directions

The research opens several promising avenues for future investigation:

1. long-term impact studies: systematic evaluation of the model complex's effectiveness in various educational contexts.
2. Model extension: development of additional model categories and applications for emerging educational needs.
3. Technology integration: investigation of integration possibilities with new educational technologies and platforms.
4. Pedagogical framework: further development of supporting didactic materials and teaching methodologies.
5. Cross-cultural implementation: study of the model complex's effectiveness in different educational systems and cultural contexts.

4.6. Final remarks

This research contributes to the advancement of mathematics education by providing a practical framework for implementing holistic educational principles through dynamic modeling. The developed complex of GeoGebra models, supported by comprehensive didactic materials, offers a scalable and effective approach to enhancing mathematical understanding. The success of this implementation suggests that similar approaches could be valuable across various educational contexts and disciplines.

The findings underscore the importance of combining theoretical rigor with practical application in mathematics education, demonstrating how technology can bridge this gap effectively. As educational technology continues to evolve, the principles and methodologies established in this research provide a foundation for future developments in mathematical education.

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Ontology-based representation and design of subject domains for Computer Science education

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Abstract
This paper presents an ontological approach for representing and designing subject domains in computer science education. An ontology schema is proposed to formally describe the key concepts, relationships, and competencies within a discipline. Criteria for selecting computer ontology systems are established, and a methodology for designing subject domain ontologies using the web-based Protégé environment is outlined. An algorithm is provided to guide future IT specialists in constructing ontologies based on the schema. Experimental results demonstrate improved speed, reduced defects, and faster integration when using the proposed ontology-based approach compared to traditional methods. The findings highlight the effectiveness of ontologies as a means to systematize knowledge and enhance the training of aspiring IT professionals.

Keywords
ontology, knowledge representation, computer science education, subject domain modeling, competency-based learning

1. Introduction

1.1. Problem statement

The development of ontology-driven information systems is a key trend in modern computing [1, 2]. Ontologies enable the formal specification of domain concepts and relationships, providing a foundation for knowledge sharing and machine processing [3, 4]. In the context of computer science education, ontologies can play a vital role in representing subject domains and supporting competency-based learning [5, 6].

However, constructing ontologies is a complex and time-consuming process that requires expertise in knowledge representation languages and techniques [7]. Computer ontology systems (COS) have emerged as tools to facilitate ontology development by providing intuitive interfaces and features [8]. Integrating COS into the training of future IT specialists is crucial for equipping them with the skills to model and reason about subject domains.

1.2. Related work

Foundational work on ontologies and their application in computer systems has been conducted by Gruber [9, 10], Lapshyn [11]. The use of ontologies to support knowledge sharing and reuse has been explored by Gruber [12], Noy and McGuinness [7]. Ovdei and Proskudina [8] provide an overview of ontology engineering tools and their capabilities.

In the educational context, Yevseeva [5], Liubchenko [13], Tsidylo [6] have investigated the use of ontologies for modeling subject domains and integrating knowledge. Tsidylo and Kozibroda [14] examine the role of COS in developing design competencies among engineering educators.

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While these works highlight the potential of ontologies in education, there is a need for a comprehensive approach that guides future IT specialists in constructing subject domain ontologies using COS.

1.3. Objectives

The objectives of this paper are:

1. To propose an ontology schema for representing subject domains in computer science education.
2. To establish criteria for selecting COS and identify a suitable environment for ontology design.
3. To develop a methodology for constructing subject domain ontologies using the selected COS.
4. To experimentally evaluate the effectiveness of the proposed approach in terms of ontology construction speed, defect reduction, and integration efficiency.

2. Ontology schema for subject domains

Figure 1 presents the proposed ontology schema for representing subject domains. The schema defines a set of core concepts (C_{DD}) and relationships (R_{DD}) to capture the key elements and associations within a discipline:

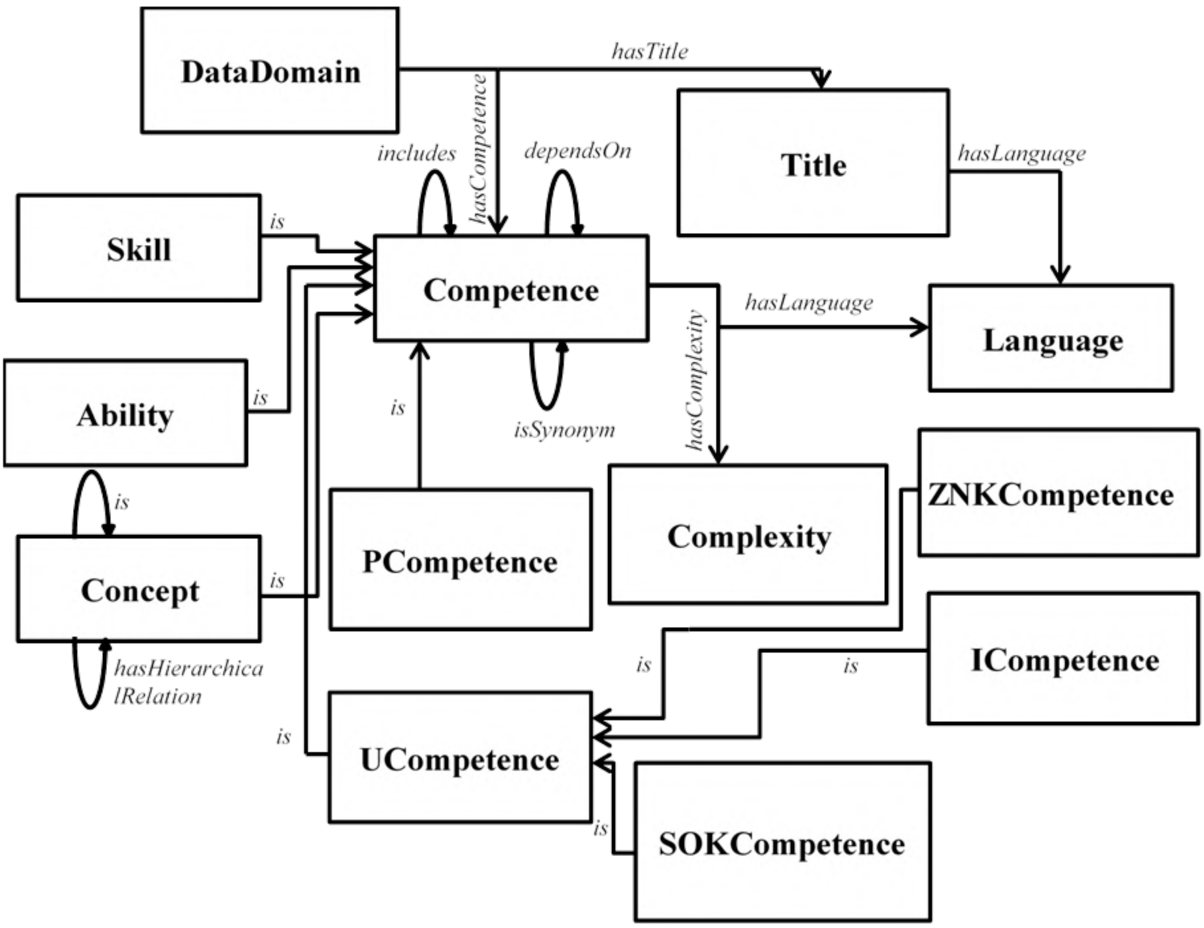

Figure 1: Ontology schema for subject domains.

The set of concepts C_{DD} includes:

- `DataDomain`: The subject domain of the discipline.
- `Competence`: The competencies associated with the discipline.

- `Concept`: The key concepts or terms within the subject domain.
- `UCompetence`, `PCompetence`, `ZNKCompetence`, `ICompetence`, `SOKCompetence`: Different types of competencies (universal, professional, general scientific, instrumental, socio-personal/cultural).
- `Skill` and `Ability`: The skills and abilities acquired within the subject domain.
- `Language`: The language used to represent the subject domain knowledge.

The set of relationships R_{DD} includes:

- `hasLanguage`: Specifies the language of the ontology.
- `hasComplexity`: Defines the level of competency development.
- `includes`: Represents the inclusion of competencies, concepts, skills, and abilities.
- `dependsOn`: Captures dependencies between competencies, concepts, skills, and abilities.
- `isSynonym`: Indicates synonymy between subject domain concepts and competencies.
- `is`: Expresses an "is-a" relationship between subject domain concepts.
- `hasHierarchicalRelation`: Represents hierarchical relationships between concepts.
- `hasTitle`: Specifies the natural language description of a competency.
- `hasCompetence`: Links a subject domain to its associated competencies.

This schema provides a foundation for formally representing the structure and elements of a subject domain in computer science education.

3. Criteria for selecting computer ontology systems

To support the design and development of subject domain ontologies, it is crucial to select an appropriate COS. The following criteria should be considered [15]:

1. Software architecture and development tools: The COS should have a robust architecture and provide tools for ontology editing, visualization, and reasoning.
2. Functional compatibility: The COS should support interoperability with other ontology languages and tools, enabling seamless integration and knowledge sharing.
3. Intuitive interface: The COS should offer a user-friendly interface that facilitates collaborative ontology development and provides access to ontology libraries.

Based on these criteria, the web-based Protégé environment [16] is identified as a suitable COS for ontology design in computer science education. Protégé offers a rich set of features, including an intuitive graphical interface, support for multiple ontology languages (e.g., OWL, RDF), and extensive reasoning capabilities.

4. Methodology for ontology design

To guide future IT specialists in constructing subject domain ontologies using Protégé, the following methodology is proposed, adapted from [17]:

1. Define the domain and scope of the ontology.
2. Reuse existing ontologies if applicable.
3. Enumerate important terms in the ontology.
4. Define classes and class hierarchy.
5. Define class properties and attributes.
6. Define facets of properties.
7. Create instances of classes.

Applying this methodology in the context of the proposed ontology schema (Section 2), the following algorithm is suggested for ontology construction:

1. Identify and describe first-level competencies (`UCompetence`, `PCompetence`, `ZNKCompetence`, `ICompetence`, `SOKCompetence`) based on the discipline's curriculum and competency matrix.
2. Identify and describe second-level competencies (`Concept`, `Skill`, `Ability`) by analyzing the acquired knowledge, skills, and abilities.
3. Identify and describe third-level competencies associated with each module of the curriculum.
4. Identify and describe lower-level competencies based on the subject domain knowledge and available educational resources.
5. Define relationships between competencies using the R_{DD} set, considering inclusion (`includes`), dependency (`dependsOn`), synonymy (`isSynonym`), and hierarchical relations (`hasHierarchicalRelation`).

Figure 2 illustrates an example of a subject domain ontology constructed using this algorithm in Protégé.

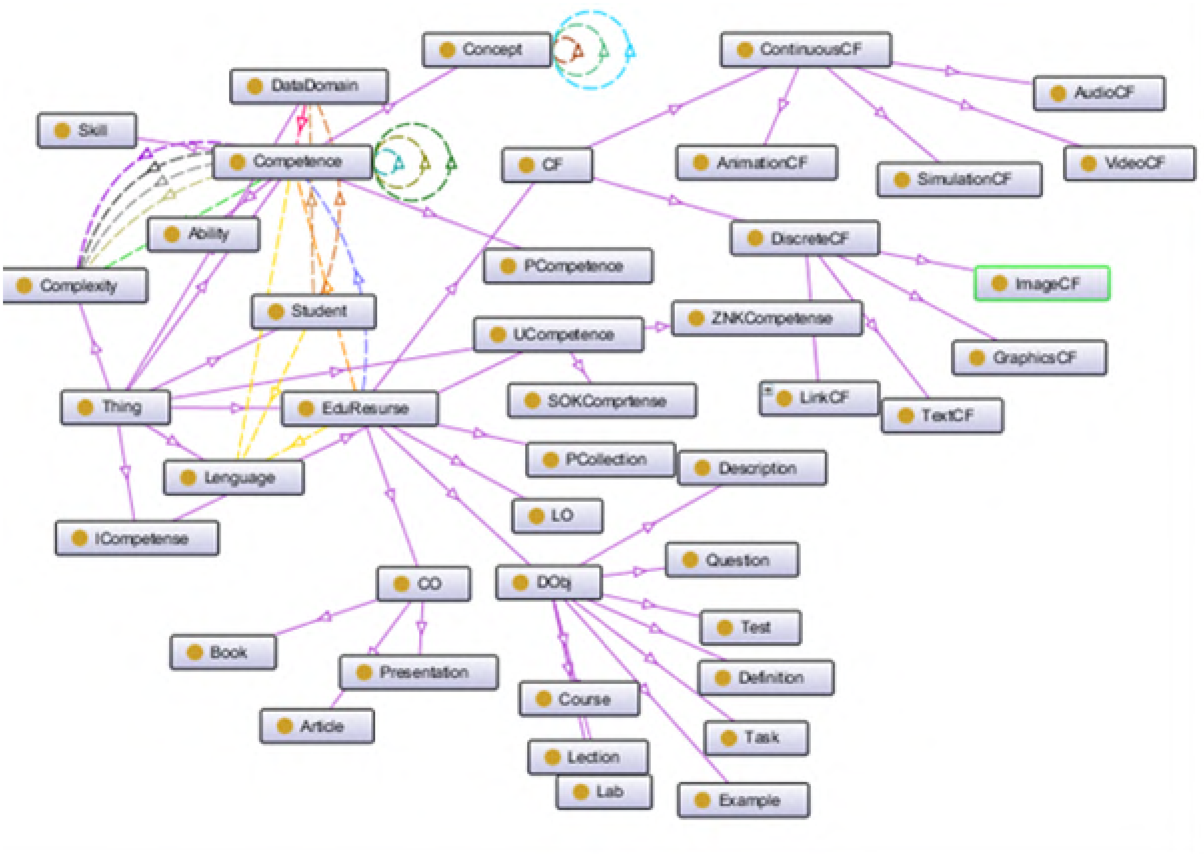

Figure 2: Example of a subject domain ontology in Protégé.

5. Experimental evaluation

To assess the effectiveness of the proposed ontology-based approach, an experiment was conducted with 40 future IT specialists divided into control and experimental groups. The experimental group used the ontology schema and methodology with Protégé, while the control group used traditional methods without COS.

The following metrics were evaluated:

1. Ontology construction speed: The experimental group completed ontology construction 2.5 times faster than the control group (figure 3).
2. Number of defects: The experimental group's ontologies had significantly fewer defects (almost 2 times) compared to the control group (figure 4).

3. Integration speed: The experimental group integrated their ontologies into a larger university ontology 3 times faster than the control group (figure 5).

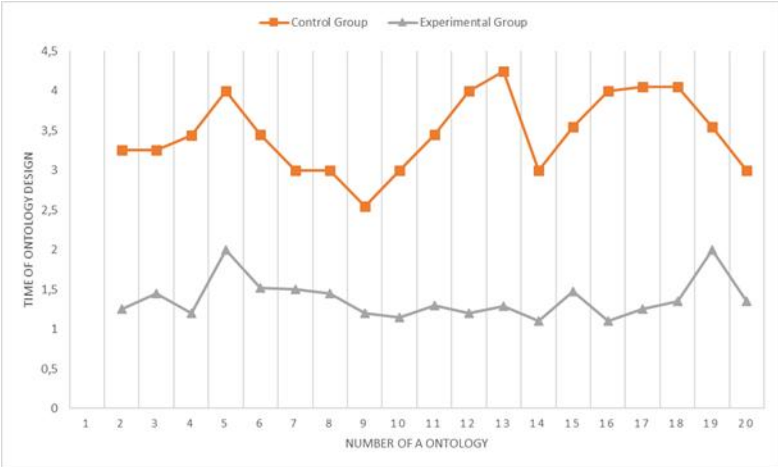

Figure 3: Comparison of ontology construction speed.

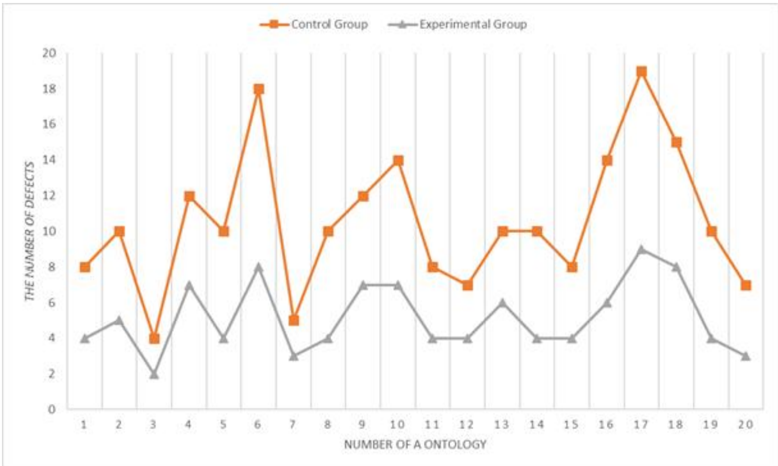

Figure 4: Comparison of ontology defects.

These results demonstrate the significant benefits of using the proposed ontology-based approach and COS in terms of efficiency, quality, and integration capabilities.

6. Conclusions

This paper presented an ontological approach for representing and designing subject domains in computer science education. The proposed ontology schema provides a formal structure for describing key concepts, relationships, and competencies within a discipline. Criteria for selecting COS were established, and the web-based Protégé environment was identified as a suitable tool for ontology design.

A methodology and algorithm were developed to guide future IT specialists in constructing subject domain ontologies using the schema and Protégé. Experimental evaluation demonstrated significant improvements in ontology construction speed, defect reduction, and integration efficiency compared to traditional methods.

The findings highlight the effectiveness of ontologies as a means to systematize knowledge and enhance the training of aspiring IT professionals. Future research directions include exploring the

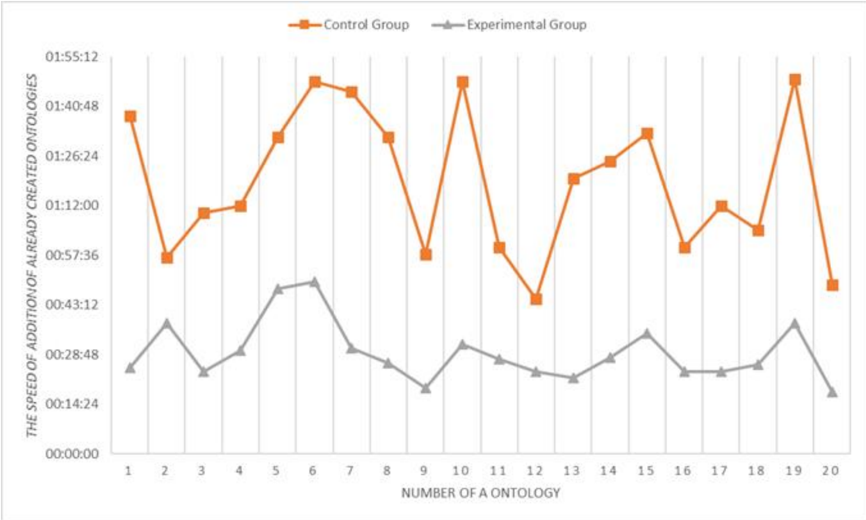

Figure 5: Comparison of ontology integration speed.

integration of constructed ontologies into intelligent tutoring systems and investigating the impact on student learning outcomes.

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Data science tools for economics education: text mining and topic modeling applications

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Abstract

Data science is the interdisciplinary field that uses tools, algorithms, and knowledge of mathematics and statistics to extract insights from data. Data science has a wide range of applications in various domains, such as business, marketing, banking, insurance, medicine, tourism, etc. Data science can also enhance the value of economics education by providing students with relevant skills and competencies for the modern and technologically advanced society. This paper explores the use of data science tools, especially text mining and natural language processing, for conducting scientific research and teaching economics. The paper demonstrates how text analytics and topic modeling can be used to analyze public perception of various topics, such as events, companies, products, and services. The paper also shows how text analytics and topic modeling can incorporate additional metadata, such as the characteristics of the comment authors, to reveal differences in their opinions. Furthermore, the paper reviews the data science study programs for economics at top-20 universities and identifies their strengths and weaknesses.

Keywords

data science, economics education, text mining, topic modeling, machine learning, natural language processing

1. Introduction

The year 2020 was a critical moment for the global society, as the COVID-19 pandemic exposed the vulnerabilities and opportunities of various sectors and domains [1, 2, 3, 4, 5]. The education sector was one of the most affected by the pandemic, as it had to undergo a rapid digital transformation, a shift to online learning, and a suspension of educational activities [6, 7, 8, 9, 10]. The field of economics also faced significant changes, such as the digitalization of processes, the adoption of remote work, and the alteration of service and communication with customers [11, 12]. The fast-paced world has become more digital than ever, and the demand for data literacy, data-driven decision making, and data science skills has increased accordingly.

Data science is an interdisciplinary field that uses tools, algorithms, and knowledge of mathematics and statistics to extract insights from data. Data science has a wide range of applications in various domains, such as business, marketing, banking, insurance, medicine, tourism, etc. However, the potential of data science in education has been relatively underexplored, and many opportunities for advancing the field have not been fully exploited.

Data science can be used in education to address scientific problems, such as in the study of behavior in economics, in macro- and microeconomics, marketing, finance, agriculture, environmental and ecological economics, and so on. Data science can also be used to enhance the teaching and learning of economics by providing students with relevant skills and competencies for the modern and technologically advanced society.

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2. Literature review

Data science has a big list of tools: linear regression, logistic regression, density estimation, confidence interval, test of hypotheses, pattern recognition, clustering, supervised learning, time series, decision trees, Monte-Carlo simulation, naive Bayes, principal component analysis, neural networks, k-means, recommendation engine, collaborative filtering, association rules, scoring engine, segmentation, predictive modeling, graphs, deep learning, game theory, arbitrage, cross-validation, model fitting, etc. Some of these tools were used in the next researches.

Teaching data science, for example, were introduced in [13], Big data and data science methods presented in [14, 15, 16, 17, 18, 19, 20], machine learning used in [21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35], Monte Carlo method presented in [36], Artificial Intelligence presented in [37, 38, 39, 40]. Data science is fast developing. A large volume of information that grows with each passing year makes it possible to build high-precision models that simplify and partially automate the decision-making process. Models are being developed that implement the key data science algorithms for different areas of economics: financial data science [41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52], for institutional economics – [53, 54, 55, 56, 57, 58], for agriculture – [59, 60, 61], for taxation – [62], and labor market – [63].

Data science developing for education discussed in [64, 65, 66, 67, 68].

3. Data science: principles and tools

Data science in education is a multidisciplinary approach to technologies, processes, and systems for extract knowledge, understanding of data, and supports decision-making under uncertainty. Data science deals with mathematics, statistics, statistical modeling, signal processing, computer science & programming, database technologies, data modeling, machine learning, natural language processing, predictive analytics, visualization, etc. Data science in education has two aspects of the application: (i) the management and processing of data and (ii) analytical methods for analysis and modeling, and includes nine main steps (figure 1). The first aspect includes data systems and their preparation, including databases facilities, data cleansing, engineering, visualization, monitoring, and reporting. The second aspect includes data analytics data mining, machine learning, text analytics, probability theory, optimization, and visualization. The basis of the learning process is the availability of relevant data that is of sufficient quality, appropriately organized for the task. Primary data often requires pre-processing. First of all, it is necessary to investigate the availability of the necessary data and how they can be obtained. The data search ends with the creation of a data set in which data coexistence is to be provided. Data science has a wide range of tools for data evaluation and preparation, in particular for data mining, data manipulation (value conversion, data aggregation and reordering, table aggregation, breakdown or merge of values, etc.) and validation of data (checking format, ranges of test values and search in legal values tables). The problem of missing values is solved by using different analytical methods: simulation, inserting default values, statistical simulation. Data science provides broad opportunities for text analytics. In addition, the use of data science tools facilitates work with big data. The main approaches in data science are supervised learning models and unsupervised learning models.

3.1. Supervised learning models

Supervised learning is one of the methods of machine learning, in which the model learns on the basis of labeled data. Using Supervised learning is possible to decide on two types of tasks: regression and classification. The main difference between them is the type of variance that is predicted by the corresponding algorithm. In regression training, it is a continuous variable, in the classification, it is a categorical variable. To solve these problems, many algorithms have been developed. One of the most common is a linear and logistic regression, a decision tree.

Linear regression. Regression analysis can be considered as the basis of statistical research. This approach involves a wide range of algorithms for forecasting a dependent variable using one or

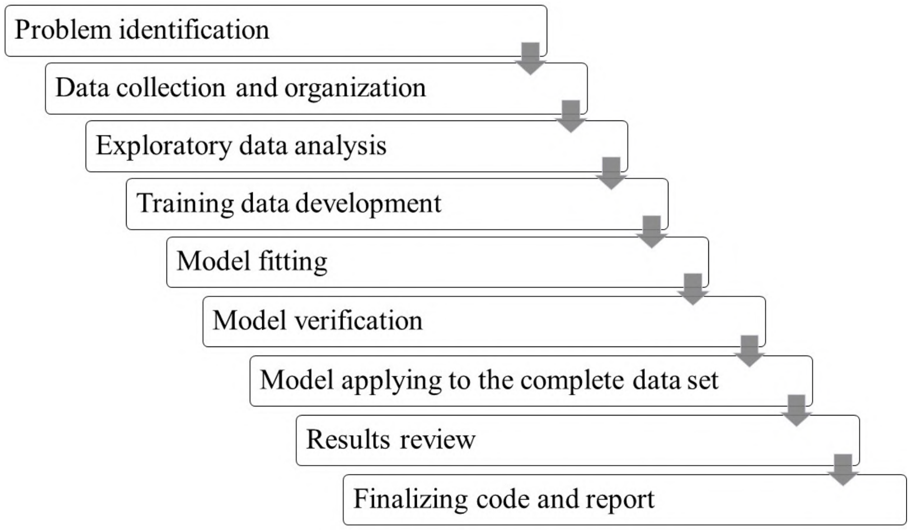

Figure 1: Data science process.

more factors (independent variables). The advantage of applying such an approach to modeling is the simplicity and clarity of the results, the speed of learning, and the release of the forecast. The disadvantage is not always sufficiently high precision (since in economics and finances, the linear relationship between changes is rare).

Logistic regression is used when it is necessary to predict the release of a binary variable using a dataset of continuous or categorical variables. Situations, where the parent variable has more than 2 possible values, can be simulated by a one-vs-all approach when constructing a logistic classifier for a possible output, or one-vs-one when constructing logistic classifiers for each possible combination of categories of the original variable. The dependence between the independent and the logarithmic variable in logistic regression is linear, the only difference with linear regression is sigmoidal functions, which converts a linear result in the probability of belonging to a class within [0; 1]. The advantages and disadvantages of logistic regression are due to the advantages and disadvantages of linear regression. This is the speed of the algorithm and the possible interpretation of the results, on the one hand, and a little accuracy – on the other. Logistic regression is often used to construct vote-counting models. An important factor in this is the interpretation of its results. The influence of each factor is clearly expressed by the magnitude of the coefficient b, which allows it to be clearly defined which of them positively and to what extent influence the decision.

A **decision tree** is an approach to both regression and classification. It is widely used in intelligent data analysis. The decision tree consists of "nodes" and "branches". The tree nodes have attributes that are used to make decisions. In order to make a decision, it is needed to go down to the bottom of the decision tree. The sequence of attributes in a tree, as well as the values that divide the leaves into branches, depends on such parameters as the amount of information or entropy that the attribute adds to the prediction variable. The advantages of decision trees are the simplicity of interpretation, greater accuracy in decision-making simulation compared with regression models, the simplicity of visualization, natural modeling of categorical variables (in regression models it is needed to be coded by artificial variables). However, the decision trees have one significant drawback – low predictive accuracy [69].

3.2. Unsupervised learning

Unsupervised learning describes a more complex situation in which, for each observation $i = 1, ..., n$, observation of the measurement vector x_i, but without any variables in the output y_i. In such data, the construction of linear or logistic regression models is impossible, since there are no predictive variables. In such a situation, a so-called "blind" analysis is conducted. Such a task belongs to the class of tasks of unsupervised learning, due to the absence of an output variable that guided the analysis. Unsupervised learning algorithms can be divided into algorithms for space reduction and clustering algorithms. The main task of clustering is to find patterns in the data that allow you to divide the data into groups and then in a certain way analyze them and give them an interpretation.

K-means is one of the most popular clustering algorithms, whose main task is to divide n observations into k clusters. The minimum sum of squares is the distance of each observation to the center of the corresponding cluster. This algorithm is iterative, at each step the cluster centers are re-indexed and redistributed observation between them until a stable result is achieved. The benefits of such an algorithm of clustering are the simplicity, speed, and the ability to process large amounts of data. But the user must specify the number of clusters he wants to use for clustering before computing; the instability of the result (it depends on the initial separation of points between the clusters).

Hierarchical clustering is an alternative approach to clustering, which does not require a preliminary determination of the number of clusters. Moreover, the hierarchical clustering ensures the stability of the result and gives the output an attractive visualization based on the tree-like structure of observations/clusters – dendrogram. This clustering algorithm uses different distance metrics and cluster agglomeration cluster criteria, which makes it very flexible to the data on which clustering is performed. However, the disadvantage of hierarchical clustering is the need to calculate the matrices of the distance between observations before agglomeration, which complicates the application of this algorithm for large data and data with many dimensions.

Time series analysis. A time series is built by observations that have been collected with a fixed interval. It could be daily demand, or monthly profit growth rates, number of flights, etc. The time series analysis takes an important part in the analysis of data that covers the region, from the analysis of exchange rates to sales forecasting [70, 71]. One of the tasks of time series analysis is the allocation of trend and seasonal components and the construction of the forecast. There are many algorithms that have been developed, and we consider models such as ARIMA and Prophet.

The **ARIMA** algorithm is one of the most common algorithms for forecasting time series. The basic idea is to use the previous time series values to predict the future. This can use any number of lags, which makes such an approach difficult in setting because it is necessary to select the parameter so as to minimize the error and not override the model. ARIMA is often used for short-term forecasting. A disadvantage is the complexity of learning a model in many seasonal conditions.

Algorithm Prophet was developed by Facebook at the beginning of 2017 for forecasting based on time series [70]. It is based on an additive model in which nonlinear trends are of annual and weekly seasonality. This approach also allows to model holidays and weekends, thereby allowing to predict residuals in a time series. Also, the Prophet is insensitive to missed values, the bias in the trend, and significant residuals, which is an important advantage over ARIMA. Another advantage is the rather high speed of training, as well as the ability to use large-scale time series.

4. Topic modeling in data science

Under the notion of texts mining in natural language we understand the application of methods of texts computer analysis and presentation in order to achieve the quality, which corresponds to the "manual" processing for further usage in various tasks and applications. One of the actual tasks of automatic texts mining is topic modelling.

4.1. Latent Dirichlet Allocation

Topic modelling is a statistical approach to extract the hidden semantics that occurs in a collection of documents or reviews. *Latent Dirichlet Allocation (LDA)* model proposed by [72] is one of the most notable approach for unsupervised topic modeling, which assumes documents and the words within them are derived from a "generative probabilistic model". Within the class of unsupervised statistical topic models, themes are defined as distributions over a vocabulary of words that represent semantically interpretable "topic" [73]. 'Meaning' of those topics (usually, in the form of topic Label and topic Description) is an emergent quality of the relationship between words [74, 75]. The task of topic meaning recognizing is often fraught with difficulty and requires the application of a triangular approach to its implementation, namely: (i) a literature review of existing topics found in the analyzed problem domain; (ii) independent work of experts on assigning labels to topics; (iii) conducting joint expert discussions in order to compare and revise the obtained labelling results.

As for main assumption of LDA method, there are the following [76]: (i) document is represented as a mixture of topics; (ii) each topic are present in many documents; (iii) each word within a given document belonging to exactly one topic; (iv) each document can be represented as a vector of proportions that denote what fraction of the words belong to each topic.

The basic LDA model is shown in figure 2.

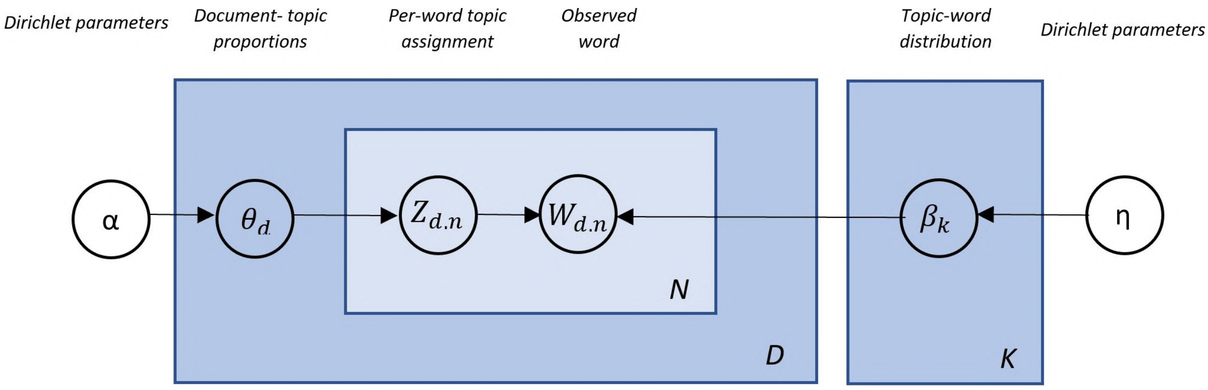

Figure 2: Latent Dirichlet allocation model [77].

Figure 2 serves as a visual explanation of the model and could be described as follows: (i) we have D documents and K topics; (ii) each topic presented by β_k words distribution over the vocabulary within the topic k; (iii) each document is presented by θ_d topic proportions within the document, where $\theta_{d,k}$ is the topic proportion for topic k in document d. Finally, we have (iv) for each n^{th} word in the document d – topic assignments $z_{d,n}$ (depends on the per-document topic proportions θ_d) and (v) for each d^{th} document – observed words $w_{d,n}$ which is an element from the fixed vocabulary (depends on the topic assignment $z_{d,n}$ and all of the topics $\beta_{1:k}$) [77].

In is obviously that data scientist in cooperation with other science domains increasingly seek ways to apply NLP and especially LDA topic modelling techniques to extract, organize, recognize, label and classify customers opinions and experiences [78]. Next examples demonstrate the possibilities to sol the apply LDA topic modelling for solving: (i) human resources management, (ii) service quality assessment, (iii) research & development policy coordination tasks and (iv) strategic planning in universities.

Kobayashi et al. [79] used topic modelling to summarize the worker attributes and find worker attribute constructs and use these to cluster jobs. 140 main topics were identified, and such skills, as, for example, interpersonal communication (vocabulary of words: communication, written, oral, verbal, interpersonal, presentation, effective, listening); analytical and problem-solving (vocabulary of words: problem, solving, analytical, solver, troubleshooting, approach, abilities, capabilities); data analytical skills (vocabulary of words: data, analysis, quantitative, research, statistics, economics, statistical, modeling); willingness to travel and the ability to operate on a flexible work schedule (vocabulary of words: travel, willingness, willing, work, time, needed, internationally, international) and other. As authors mentioned, topic modelling showed that it is not only possible to classify job information from vacancies but that we can also derive behavioral characteristics that are valued or required by employers from potential or existing job holders. Moreover, as a further analysis of this research was planned the analysing trends of worker attributes required by organizations (i) over time, (ii) occupations, companies, and (iii) geographical regions, and also (iv) possibility to build a network of work activities to examine relationship among tasks.

Wallace et al. [80], Sharma et al. [81] captured the main positive and negative words within latent aspects (topics), which characterise interpersonal manner, technical competence, and systems issues

[82] from online physician reviews. Similar with previous work, James et al. [83] based on López et al. [82] categorization, examined unstructured textual feedback of physicians in order to determine: (i) how the extracted sentiment and topics compared to traditional identified dimensions of service quality in healthcare and (ii) what tone and topic elements were driving patients' service quality ratings. As a main finding were the following list of topics and their tone: (1) Negative system quality: Staff and Timeliness (vocabulary of words: office, staff, time, doctor, wait, appointment); (2) Positive interpersonal quality: Physician Compassion (vocabulary of words: doctor, caring, great, knowledgeable, excellent, recommend); (3) Negative system quality: Experience (vocabulary of words: told, don't, doctor, ask, bad, money, call); (4) Positive Technical quality: Family (vocabulary of words: doctor, questions, staff, practice, children, son, pregnancy); (5) Positive Technical quality: Surgery (vocabulary of words: surgery, pain, procedure, staff, hospital, knee, cancer, age); (6) Negative Technical quality: Diagnosis (vocabulary of words: years, treatment, medical, patient, conditions, test, diagnosis, time, treated). The obtained results allowed the authors to establish the dependence on the degree of influence of the identified aspects (topics) on the general perception of the physician's quality, as well as the behavioural characteristics of patients when choosing a doctor online, depending on the content of comments and overall rating.

4.2. Structural topic modelling

When conducting research on the basis of textual documents or customers comments, researchers often have a more of information "about the text" than "about the content of the text". From the perspective of topic modelling as a statistical approach, the existence of such information "about the text" (metadata) allows and initiates the inclusion in the model of additional covariates that could influence the following components of the topic model: (1) Proportion of the document devoted to the topic ("prevalence of the topic"). For example, we can know that "clients who buy products online are more likely to talk about delivery problems than clients who buy offline". (2) Word rates used in the discussing of the topic ("topical content"). For example, we can clarify that "when clients talking about delivery problems, clients who buy products online are more likely discuss the problems about products returning, but patients clients who buy offline are more likely discuss staff rudeness issues" [84]. Such possibilities are proposed by *Structural topic modelling (STM)* as an extension of the LDA framework [74, 84, 85] .

Drawing analogies with LDA: (i) each document in STM arises as a mixture over K topics; (ii) topic proportions (θ_d) can be correlated (LDA limitation 1); (iii) topics prevalence θ_d can be influenced by set of covariates X through a standard regression model with covariates; (ii) for each w_n word in the document d (iii) a topic $Z_{d,n}$ is drawn from the document-specific distribution, and (iv) conditional on that topic, a word is chosen from a multinomial distribution over words parameterized by $\beta_{d,k,v}$, where $k = Z_{d,n}$. This distribution can include a second set of covariates Y [84]. Thus, the main differences between the LSA and STM models (figure 3) are that the prevalence (content) parameters determined in the LDA by the general a priori Dirichlet parameters $\alpha(\eta)$ in the STM model are replaced with prior structures specified in the form of generalized linear models parameterized by document specific covariates $X(Y)$ [86] These covariates inform either the topic prevalence (covariates X) or the topical content (covariates Y) latent variables with information "about the text" (metadata).

5. Example of structural modelling algorithms application in education

In order to study customer perception of the quality of services, assess their satisfaction with goods or services received, as well as identify factors that influence customer acceptance of new offers on the market, students were asked to use STM tools. As a data source 610 textual comments about hospitals from the site http://www.ratemyhospital.ie/ (over the past two years – 2018–2019) were used. STM package allows to use all additional variables to demonstrate the power of meta-data for topic modelling. With this aim, textual comments data was extended by information about (1) hospital ownership (private, public), (2) sentiment (positive or negative) (table 1) [87]. After that, all steps of text pre-processing

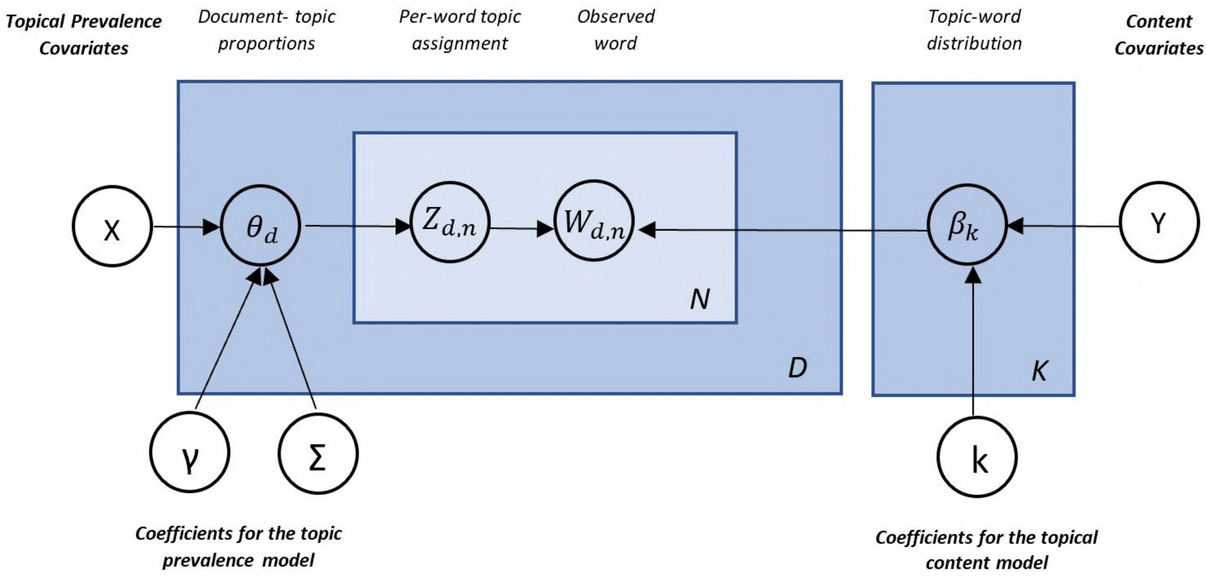

Figure 3: A graphical illustration of the structural topic model [76].

were performed.

Table 1
Comments before pre-processing.

Comments	Hospital Ownership	Sentiment
A lovely friendly patient-focussed hospital	Public	Positive
Consultant I found seriously lacking compassion for my mother the patient. Sniggered while informing us that while my mother's condition is uncomfortable, it is not life threatening.To be frank, consultant spoke down to us.	Public	Negative
Tullamore is a very clean hospital and looks very well. All staff I had the pleasure of meeting were lovely and very professional at all times. The staff in all capacities do not receive enough thanks for the jobs they do	Private	Positive

First, the STM model's setup were performed. To determine the optimal number of topics, STM models from 10 till 30 topics were built were analyzed. Semantic coherence is maximized when the most probable words in a given topic frequently co-occur together, and it is a metric that correlates well with a human judgment of topic quality. Having high semantic coherence is relatively easy, though, if we only have a few topics dominated by very common words, so we wanted to look at both semantic coherence and exclusivity of words to topics. So, the most valuable number of topics should be very coherent and also very exclusive. Looking at figure 4, we draw the conclusion that the 15 topics suit the most to these criteria. Most of the topics, in this case, are above the average of exclusivity and have high coherence, especially compared to the other number of topics which are often spread out on both axes. 15-topic STM model was selected based on subjectively optimal combination of the average semantic coherence and exclusivity outcomes.

As a result, for 15-topic model, we received the (i) topic-words distribution β; (ii) document-topic proportions θ; (iii) list of Highest probability-, FREX-, Lift- and Score-keywords (*Highest Prob*: are the words within each topic with the highest probability; *FREX*: are the words that are both frequent and exclusive, identifying words that distinguish topics; *Lift*: give more weight to words that appear less frequently in other topics by dividing their frequency into other topics; *Score*: score words are weighted by dividing the log frequency of the word in the topic by the log frequency in other topics [85, 88, 89]); (iv) set of documents, mostly associated with this topic. The figure 5 allows us to get information on

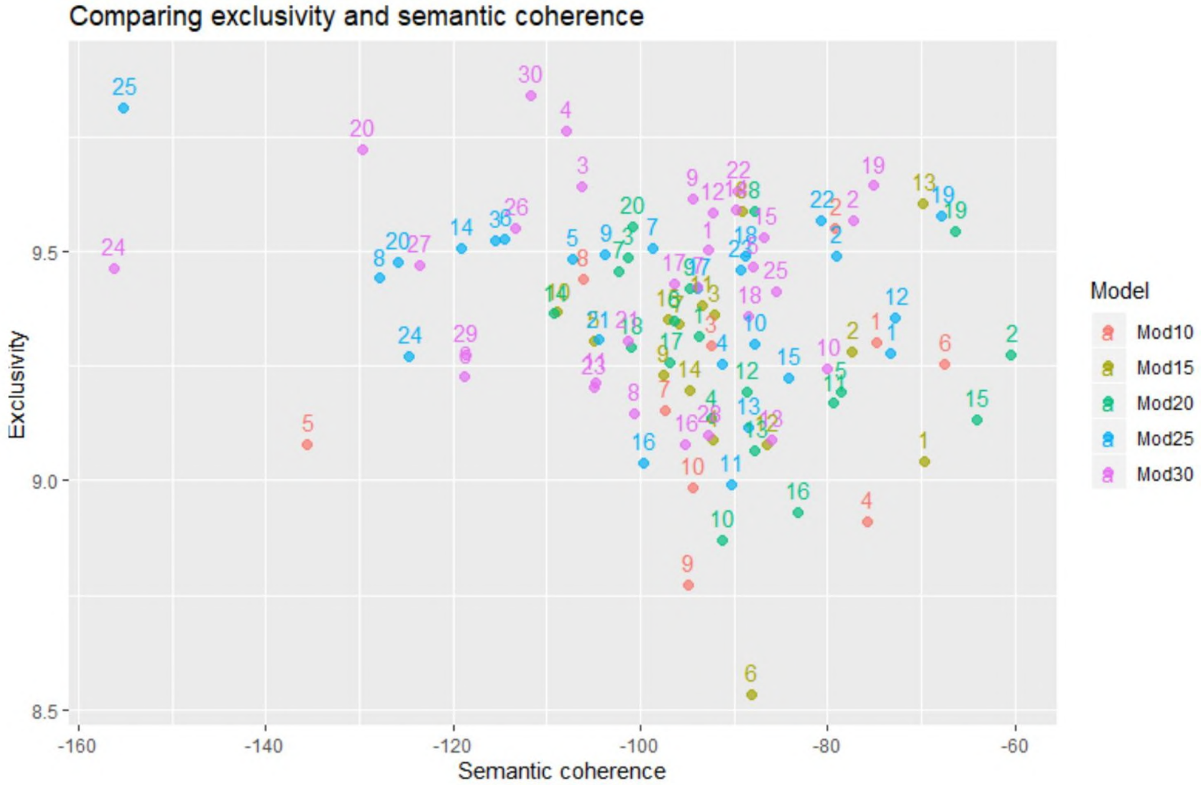

Figure 4: Semantic coherence and exclusivity of STM models.

the share of the different topics at the overall corpus.

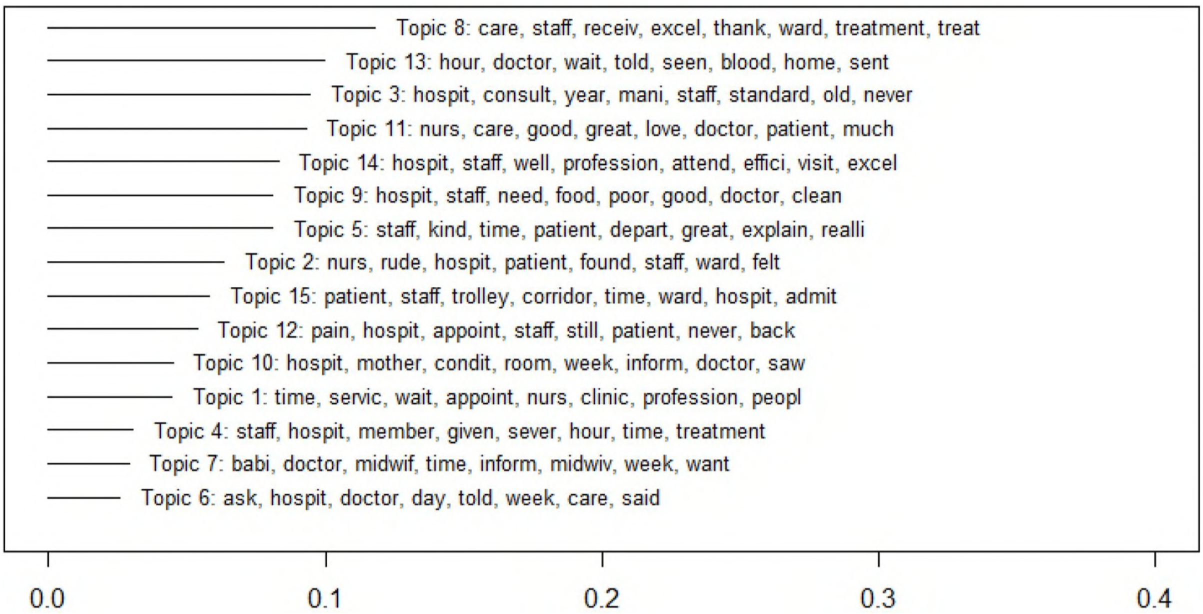

Figure 5: Expected topic proportions over corpus.

Second, students needed to realize the *Topics labelling* step. For that: (1) two students independently labelled the topics to produce the first version of labels based on top weighted keywords; (2) two students discussed the labels and resolved discrepancies in labelling; (3) two students independently refined topic labels based on the computationally guided deep reading 20 of the most representative tweets of the topics; (5) two students agreed on final 15 topic labels and jointly developed the topics descriptions (short summarization of the topic content) [87]. The result of topic labelling is presented in the table 2.

Table 2
Topics labels.

#	Topics label	Topic keywords	Topic proportion, %
1	Appointment Time Reliability	time, service, wait, appoint, nurses, clinic, profession	4.47
2	Communication Skills	nurses, rude, hospital, patient, found, staff, ward	6.34
3	Service Standards	hospital, consult, year, many, staff, standard, old	9.45
4	Waiting Time	staff, hospital, member, given, sever, hour, time	3.03
5	Staff Feedback/Explanation	staff, kind, time, patient, depart, great, explain	8.09
6	Patient-Focusing Service	ask, hospital, doctor, day, told, week, care	2.56
7	Maternity Unit/Care	baby, doctor, midwife, time, inform, midwife, week	2.89
8	Personnel Reliability / Treatment	scare, staff, receive, excel, thank, ward, treatment	11.81
9	Food Service	hospital, staff, need, food, poor, good, doctor	8.10
10	Hospital Environment	hospital, mother, conditions, room, week, inform, doctor	4.48
11	Care and Recovery	nursed, care, good, great, love, doctor, patient	9.29
12	A&E/Admission	pain, hospital, appoint, staff, still, patient, never	5.37
13	Information Exchange with Patient/Family	hour, doctor, wait, told, seen, blood, home	9.99
14	Service Rapidness	hospital, staff, well, profession, attend, efficiency, visit	8.31
15	Ward/Hospital's Facilities	patient, staff, trolley, corridor, time, ward, hospital	5.82

Third, the STM covariate analysis could be performed. In this stage, we aimed the evaluating the *Sentiment* effect on the formation of more positively and more negatively oriented aspects of hospitals service quality (HSQ). Thus, we use Sentiment metadata as Covariate in the STM model. Formally, we can identify an aspect as negative if, according to the results of effect estimation, the proportion of this aspect in negative comments (Sentiment = Negative) is significantly higher than in comments in positive comments (Sentiment = Positive). According to the results of our experiment, 5 topics (33.33%) are positive (right side of figure 6), and 10 topics (66.66%) are negative (left side of figure 6).

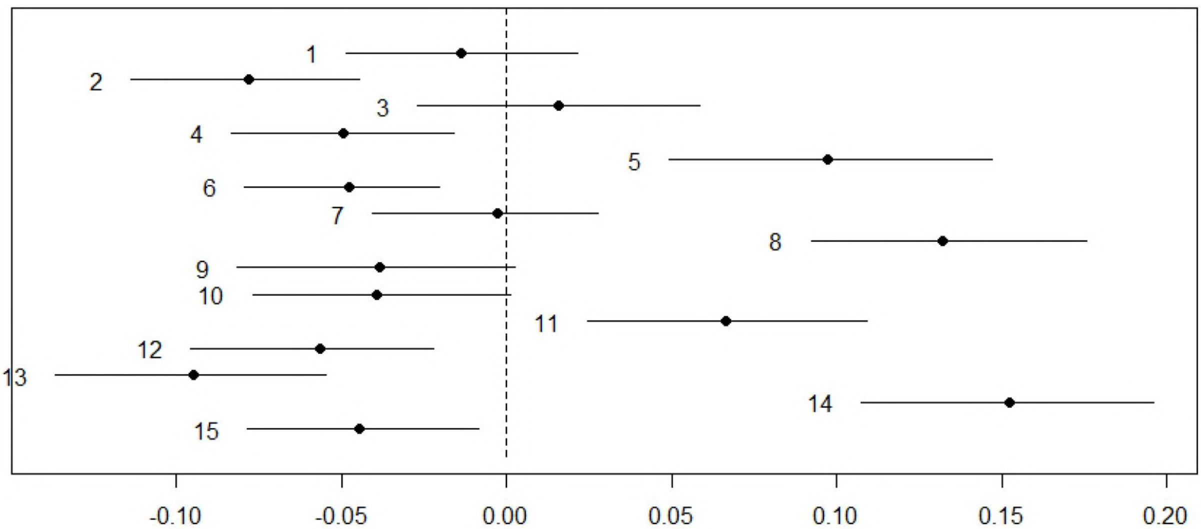

Figure 6: Difference in the power of Sentiment influence on topic proportion.

The dots in the figure 6 indicated the mean values of the estimated proportion differences (power of influence, PI) with 95% confidence intervals, allows us to evaluate the relative degree of influence of sentiment on of hospitals service quality aspects. For example, the five most negative Topic of are (1) *Information Exchange with Patient/Family* (Topic 13) with highest power of negative influence;

(2) *Communication Skills* (Topic 2); (3) *A&E/Admission* (Topic 12), (4) *Waiting Time* (Topic 4) and (5) *Patient-Focusing Service* (Topic 6). In turn two most positive topics are (1) *Service Rapidness* (Topic 14); (2) *Personnel Reliability/Treatment* (Topic 8). Knowledge about Topics with a positive and negative impact of comments Sentiment allow to indicate the strength of patient satisfaction/dissatisfaction with the hospitals service quality.

Fourth, the power of *Time* influence on positive and negative Topics dynamics (from 2018 to 2019) using the STM model (with Year and Sentiment as a Covariates) should be performed. In terms of the Influence of the Time Factor on the Service Quality, the following four groups of HSQ Topics can be distinguished: (1) Topics causing the growth of patient satisfaction with the Service Quality over the time: positive topics with a positive dynamic over the time; (2) Topics causing a recession in patient satisfaction with the hospitals service quality (HSQ) over the time: positive topics with a negative dynamic over the time; (3) Topics causing the growth of patient dissatisfaction with the HSQ over the time: negative topics with a positive dynamic over the time (4) Topics causing a recession in patient dissatisfaction with the HSQ over the time: negative topics with a negative dynamic over the time.

As an indicator that allows us to identify the direction and growth rate (GR) of change in the level of positive or negative comments describing the Topic, the slope of the regression (dependence between the proportion of Positive/Negative Aspects and Time) will be used. The presented four charts (figure 7 a, b, c, d) show examples of four possible types of Influence of the Time Factor on the Service Quality:

1. Positive impact on Service Quality over the time: Service Rapidness topic characterized by growth rate (GR=1.100763) of patient satisfaction with the HSQ over the time (figure 7, b);
2. Worsening of Service Quality over the time: Personnel Reliability/Treatment topic characterized by and recession (GR=0.821713) in patient satisfaction with the HSQ over the time (figure 7, a);
3. Negative impact on Service Quality over the time: Information Exchange with Patient/Family topic characterized by growth (GR= 1.758421) of patient dissatisfaction with the HSQ over the time (figure 7, d);
4. Improvement of Service Quality over the time: Food Service topic causing a recession in customer dissatisfaction (GR= 0.575861) with the HSQ over the time (figure 7, c).

As a result, student could see that the largest number of aspects (37.5%) has a negative impact on the HSQ. The highest degree of growth in patient dissatisfaction is characterized by *A$E/Waiting Time* topic. Moreover, this growth rate is not only the largest in the category of Negative impact, but in all analyzed topics. The most rapid (within the whole set of topics) decrease in the number of positive comments is characterized by the aspect of *Maternity Unit/Care*. The group of topics on which improvement in their quality is noted is 25.1%. At the same time, the Hospital Environment is characterized by the highest rate of improvement. 16.7% of topics have a positive effect on the HSQ, among which *Service Rapidness* and *Maternity Unit/Treatment* have the largest increase in the number of positive comments.

Fifth, students may identify the influencing the *Hospital Ownership* on more positively and more negatively oriented HSQ aspects structure (using the Sentiment and Hospital Ownership factors as in the Covariates STM model). For this purpose, the following interpretation of the results could be proposed: (1) the Topics, more related to Public Hospital Ownership according to the results of effect estimation, in which the proportion of this Topics in comments about Public hospitals (Hospital Ownership = Public) is significantly higher than in comments about Private hospitals and vice versa; (2) the direction (positive or negative) of Hospital Ownership influencing on HSQ. For reaching the first purpose, the Hospital Ownership effect estimation was performed for revealing the aspects in which the proportion of the comments about Public hospitals (Hospital Ownership = Public) is significantly higher than comments about Private hospitals and vice versa.

For formalization the rules for second purpose reaching, in terms of discovering the Influence of the Hospital Ownership on the Service Quality, the following groups of aspects proposed to be distinguished: (1) Topics causing the growth the level of patients satisfaction with Service Quality in Public hospitals: positive topics with a positive dynamic from Private to Public; (2) Topics causing the growth in the level of patients satisfaction with Service Quality in Private hospitals: positive topics with a positive dynamic from Public to Private; (3) Topics causing the growth the level of patients dissatisfaction with

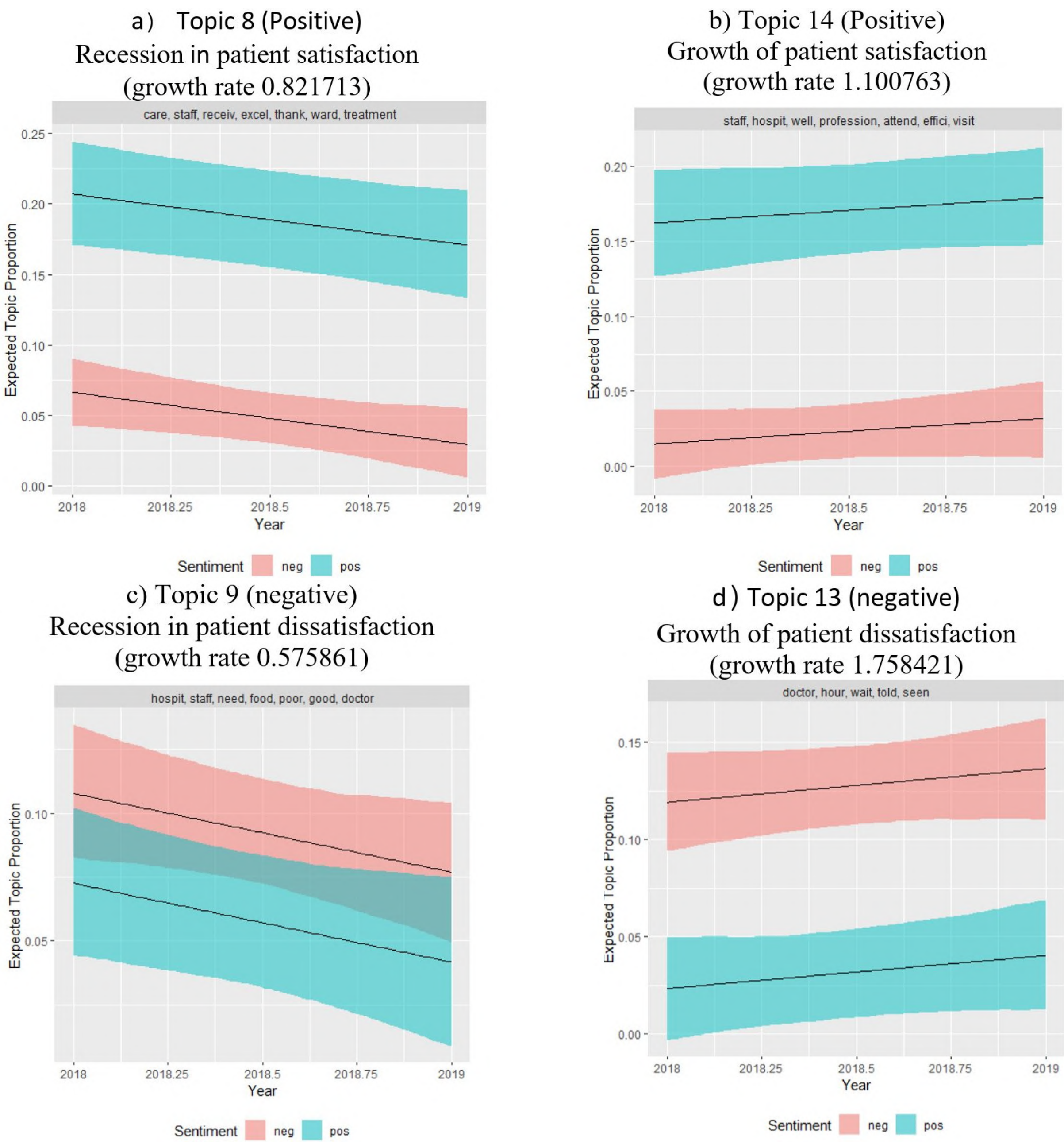

Figure 7: Examples of identification the influence of the Years Metadata.

Service Quality in Public hospitals: negative topics with a positive dynamic from Private to Public; (4) Topics causing the growth in the level of patients dissatisfaction with Service Quality in Private hospitals: negative topics with a positive dynamic from Public to Private.

According to the results of our experiment, 8 Topics are more associated with Public Hospitals (right side of figure 8), and 6 Topics are more associated with Private Hospitals (left side of figure 8), and one topic (Topic 13) is for both types of hospitals. Based on received results, we can conclude that the four topics (one positive and 3 negative), which more characterize the Public Hospital Ownership are (1) *Service Rapidness* (positive); (2) *Food Service* (negative) (3) *Maternity Unit/Care* (negative) and (4) *Patient-Focusing Service* (negative). In turn five Aspects, which more characterize the Private Hospital Ownership (two positive and two negative) are (1) *Appointment Time Reliability* (negative); (2)*Service Standards* (positive); (3) *Staff Feedback/Explanation* (positive) and (4) *Hospital Environment* (negative).

Thus, this example of the use of STM modeling in teaching students shows how versatile and in-depth research can be carried out using data science. Presented examples demonstrate the nature of tasks and

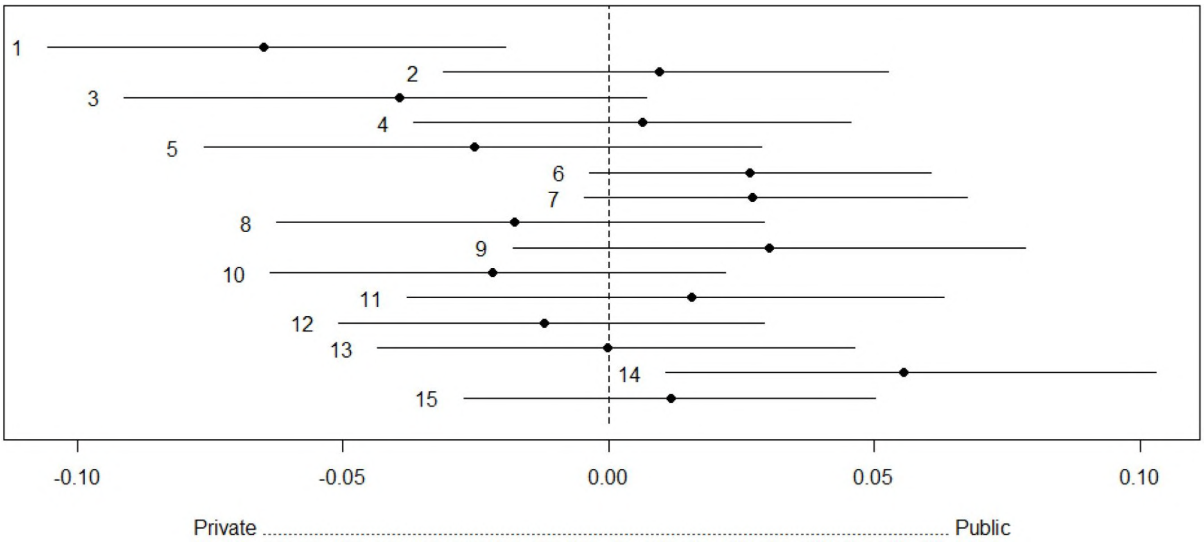

Figure 8: Difference in the power of Hospital Ownership influence on Topic Proportion.

approaches which could develop students' technical and research skills in the public perception analysis. Such approaches also allow students to gain *practical experience* in the study and interpretation the influence of additional metadata, characterizing the comments authors, on differences in their opinions about events, companies, goods, and services.

6. Data science study programs in economics field

Classical methods of statistical analysis, modeling methods, and data mining are used in economics. The analysis of data in these areas is aimed at the study of causation. In economics, current issues include policy development, determining the impact of a decision, long-term and short-term planning and forecasting, choosing the best solution from many possible, and many others. Drawing conclusions is also important in economics. In addition, the modern economy and finance are characterized using big data, so it is not always possible to use classical methods. Therefore, the methods of data science are precisely those methods that should be used in economics, which gives positive results and effect. Data science methods were first used in economic research and gradually penetrated into practice. Today, economics need specialists who have knowledge in these areas and are able to apply data science methods. In response to this market need, universities have begun to implement data science courses and programs for students of economics. The table 4 presents the courses and programs of the top 20 universities in the world.

A study programs in economic field in Ukrainian universities has shown that data science courses and programs are still being introduced in Ukraine. Currently, there are separate programs for studying Data Science, mainly for computer science. Therefore, we believe that the prospects that data science opens for modern economists necessitate the introduction of courses and programs in data science.

7. Conclusions

Data science is a rapidly growing and evolving field that has applications in various domains, such as research, society, and business. Data science requires significant investments and innovations from businesses and governments, as well as adequate education and training for students and professionals. However, as our research has shown, the integration of data science in economics education is still in its infancy. Only a few leading universities offer data science courses and programs for economics students, but this trend has not been widely adopted and needs to be further developed.

Table 3
Data science courses and programs for economics at top-20 universities.

University	Location	Programs, courses
Massachusetts Institute of Technology (MIT)	United States	MicroMasters Program in Data, Economics, and Development; Policy Computer Science, Economics and Data Science – course
Stanford University	United States	M.S. in Statistics: Data Science; Tackling Big Questions Using Social Data Science – course
Harvard University	United States	Data Science for Business – course; Using Big Data Solve Economic and Social Problems – course
California Institute of Technology	United States	Business Analytics – course
University of Oxford	United Kingdom	MSc in Social Data Science
ETH Zurich - Swiss Federal Institute of Technology	Switzerland	Data Science in Techno-Socio-Economic Systems – course
University of Cambridge	United Kingdom	Economics: Data Science and Policy – course
Imperial College London	United Kingdom	MSc Business Analytics
University of Chicago	United States	Economic Policy Analysis – course
UCL	United Kingdom	Economics and Statistics BSc; Social Sciences with Data Science BSc
National University of Singapore	Singapore	Master of Science in Business Analytics
Princeton University	United States	Statistics and Machine Learning – course
Nanyang Technological University	Singapore	Master of Science in Analytics
EPFL	Switzerland	Master's program in Data science
Tsinghua University	China (Mainland)	Master's Program in Data Science
University of Pennsylvania	United States	Master of Information Systems Management, Business Intelligence and Data Analytics; MS in Information Technology, Business Intelligence and Data Analytics; Online Master of Science in Business Analytics
Yale University	United States	Applied Econometrics: Politics, Sports, Microeconomics; Applied Econometrics: Macroeconomic and Finance Forecasting
Cornell University	United States	Introduction to Data Science – course
Columbia University	United States	Data Science for Social Good - summer program
The University of Edinburgh	United Kingdom	Statistics with Data Science MSc

As an example of the use of data science methods in economics education, we have demonstrated the application of STM-modeling in teaching students. STM-modeling is a technique that allows analyzing textual data and identifying latent topics based on additional metadata, such as the characteristics of the text authors. STM-modeling can help students develop their technological and research skills, work with big data, and study and interpret the differences in opinions about various topics, such as events, companies, products, and services.

The STM-modeling technique is just one of the many methods and algorithms that can be used for modeling and analyzing economic processes. There are numerous examples of how data science can be applied in economics education, such as using time series analysis to predict the future value of a cryptocurrency, using regression models to determine customer loyalty or the likelihood of customer insolvency, etc. Data science offers a rich set of tools and techniques that can enhance the learning and teaching of economics.

Education should keep pace with the modern development of the digital economy, digital society, innovation, and creative entrepreneurship. The use of data science in education should be cross-platform, that is, used not only in the study of specific subjects, but also in the teaching of all subjects, interaction of students with each other and with teachers, real experts, research, and individual learning.

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A model of application and learning of cloud technologies for future Computer Science teachers

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Abstract

Cloud technologies are emerging as a powerful tool for computer science education, as they offer various benefits such as scalability, accessibility, and collaboration. However, the training of future computer science teachers for the use of cloud technologies requires a systematic and comprehensive approach that covers both the theoretical and practical aspects of cloud computing. This paper presents a model of application and learning of cloud technologies in the process of training future computer science teachers. The model is based on the following principles: systematic, gradual, and continuous. The model consists of four components: target, content, operational, and effective. The model also defines three stages of using cloud technologies: as a means of organizing learning activities, as an object of study, and as a means of development. The paper also describes the design and implementation of a cloud-based learning environment (CBLE) that supports the proposed model. The CBLE is based on a hybrid cloud model that combines public and private cloud platforms. The CBLE also integrates cloud and traditional learning tools to provide a rich and diverse learning experience. The paper discusses the most suitable teaching methods for cloud technologies, such as classroom learning, interactive and e-learning, and practical methods. The paper provides several examples of how to apply the proposed model and methods in real learning scenarios. The paper evaluates the effectiveness of the proposed model and methods by conducting a pedagogical experiment. The paper uses various diagnostic tools, such as questionnaires, tests, laboratory and competency tasks, to measure the learning outcomes and satisfaction of the students. The paper performs a quantitative analysis of the experimental results and verifies their reliability using statistical methods.

Keywords

cloud technologies, computer science education, teacher training, cloud-based learning environment

1. Introduction

The digital transformation [1] of various sectors and domains of society has increased the demand for information and communication technologies (ICT) in education. ICT can provide access, flexibility, and innovation to the learning process, as well as enhance the skills and competencies of learners and educators [2, 3, 4, 5, 6, 7, 8]. One of the emerging ICT tools that has a great potential for education is cloud computing. Cloud computing is a remote computing model that allows users to access and use various resources and services over the Internet, such as storage, processing, software, platforms, etc. Cloud computing can offer various benefits for education, such as scalability, availability, and collaboration [9, 10, 11, 12, 13]. Cloud computing can enable learners and educators to work with educational materials regardless of their hardware, software, and geographical location [14, 15, 16, 17, 18]. Therefore, the study and use of cloud computing is essential for the curricula of colleges and universities, especially for the fields related to computer science and informatics.

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The aim of this paper is to design content and methods for teaching cloud computing to future computer science teachers.

The following objectives are set to achieve the aim of the research:

1. To analyze the current state of cloud computing education at leading foreign and Ukrainian universities.
2. To define the concept and principles of teaching cloud computing to future computer science teachers.
3. To propose content and methods for teaching cloud computing.
4. To conduct an experimental verification of the proposed content and methods.

The object of the study is the training process of computer science teachers.

The subject of the study is a model of teaching and learning cloud computing by future computer science teachers.

We used a combination of research methods: theoretical – analysis of scientific and technical literature, experience; generalization of experience of using cloud computing in education; empirical: observation, analysis, modeling method, methods of mathematical statistics.

2. Analysis of cloud computing learning experience

Cloud technology training is on the list of courses from leading US and European universities. Some of them are focused on the study of individual cloud platforms, while others involve the study of the theoretical foundations of cloud technologies. One major subject is administration training, while other students are learning to develop cloud applications.

For example, at Harvard University, students are offered a course in Fundamentals of Cloud Computing with Microsoft Azure. The content of this course covers the fundamental architecture and design patterns necessary to build highly available and scalable solutions using key Microsoft Azure platform as a service (PaaS) and server less offerings. The students learn fundamentals necessary to make a system ready for users, including always-up architecture and deployment strategies, rollback strategies, testing in production, monitoring, alerting, performance tuning, snapshot debugging in production, and system health analysis using application insights and analysis services [19].

Berkeley University offers a Cloud Computing: Systems course. In this course, teachers describe the technology trends that are enabling cloud computing, the architecture and the design of existing deployments, the services and the applications they offer, and the challenges that needs to be addressed to help cloud computing to reach its full potential. The format of this course will be a mix of lectures, seminar-style discussions, and student presentations. Students will be responsible for paper readings, and completing a hands-on project [20].

Cambridge University invites students to study cloud computing. This course aims to teach students the fundamentals of cloud computing covering topics such as virtualization, data centres, cloud resource management, cloud storage and popular cloud applications including batch and data stream processing. Emphasis is given on the different backend technologies to build and run efficient clouds and the way clouds are used by applications to realize computing on demand. The course includes practical tutorials on different cloud infrastructure technologies. Students assessed via a Cloud based coursework project [21].

At the University of Helsinki, students take the Cloud Computing Fundamentals: AWS course. Students learn how to use Amazon Web Services as a cloud computing platform. This course covers topics required for AWS Developer Associate certification. The course involves the creation and use of a trial account on AWS [22].

Yale University offers a Cloud Networking and Computing course. In this course, students will visit the critical technology trends and new challenges in cloud and data center designs for different trade-offs of performance, scalability, manageability, and cost in the networking layers and big data analytical frameworks. This course includes lectures and system programming projects [23].

Another approach is to study cloud technology in research labs and training centers. At MIT there is a laboratory called "Parallel & Distributed Operating Systems Group". Teachers and students have conduct research in cloud systems, multi-core scalability, security, networking, mobile computing, language and compiler design, and systems architecture, taking a pragmatic approach: they build high-performance, reliable, and working systems [24].

The California State Polytechnic University is implementing a project to create a data center training facility through a partnership between the university and leading cloud platform developers (Microsoft, Avanade, Chef, Juniper). The Center is engaged in the deployment of a corporate cloud, through which practitioners will teach students the design, configuration, implementation and maintenance of cloud services and platforms [25].

Another promising way to acquire ICT competencies is to study with massive open online courses (MOOCs) [26, 27]. Students have the opportunity to acquire knowledge independently when they study in them. Universities can also integrate these courses into their own subject disciplines. Leading online platforms offer many cloud technology training courses.

For example, there is an Introduction to Cloud Infrastructure Technologies course on the EdX platform. It contains many chapters. These include basic: Virtualization, Infrastructure as a Service (IaaS), Platform as a Service (PaaS), Containers and the latest such as Tools for Cloud Infrastructure, Internet of Things, How to Be Successful in the Cloud [28].

Coursera offers several courses to study: Essential Cloud Infrastructure: Foundation, Essential Cloud Infrastructure: Core Services, Elastic Cloud Infrastructure: Scaling and Automation, Google Cloud Platform Fundamentals: Core Infrastructure. These courses explore the Google Cloud Platform and AWS platforms [29]. In addition to high-quality educational content, the Courser platform provides access to the Google Cloud Platform and Amazon Web Services with the QuickLabs service. There, students can not only perform laboratory tasks, but also check the quality of their performance.

Udacity has developed a Become a Cloud Dev Ops Engineer nanodegree program. It provides learn to design and deploy infrastructure as code, build and monitor pipelines for different deployment strategies, and deploy scalable microservices using Kubernetes. At the end of the program, students will combine new skills by completing a capstone project [30].

The Computing Curricula 2017 document that is used in the development of IT education standards in the IT domain ITS-CCO (Cloud Computing) involves the study of such chapters [31].

ITS-CCO-01 Perspectives and impact;
ITS-CCO-02 Concepts and fundamentals;
ITS-CCO-03 Security and data considerations;
ITS-CCO-04 Using cloud computing applications;
ITS-CCO-05 Architecture;
ITS-CCO-06 Development in the cloud;
ITS-CCO-07 Cloud infrastructure and data.

Researchers and teachers from Ukrainian universities are also developing cloud computing courses. For example, the standards of the specialty "123 Computer Engineering" defined the ability of a specialist to analyze and design high-performance computer systems with different structural organization using the principles of parallel and distributed information processing [32]. The course "Cloud Technologies and Services" was developed in National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute". This course covers the following topics: Cloud technologies and services, Cloud security, Service Models, Google App Engine for Java platform, RESTful API build in Java. The Cloud Technologies course is taught at the Shevchenko National University's Faculty of Information Technologies. The course covers basic information about the emergence, development and use of cloud computing technologies. Typologies of cloud deployment (private, public, hybrid, public, etc.), cloud computing service models (SaaS, PaaS, IaaS, etc.) are considered. The discipline provides an overview of the modern solutions of the leaders of the cloud computing market – Amazon, Microsoft and Google. The advantages and disadvantages of cloud computing models and their solutions are considered. To develop practical skills in the discipline, it is proposed to deploy transactional web applications in cloud environments, transfer ready-made solutions to them, learn how to administer them, and work with virtualization technologies [33].

3. Designing a cloud computing training model

Teaching future IT teachers the use of cloud technologies is also relevant. Usually, the pedagogical universities of Ukraine study courses focused on the use of cloud technologies in education. Most of them focus on the study of public clouds of Google Suite or Microsoft Office 365 [34, 35, 36].

In general, Ukrainian and European universities use cloud platforms to create their own cloud-based learning environment (CBLE). Vakaliuk [37, 38] is developing a methodology for using cloud computing to train informatics teachers and postgraduate students.

We interpret the concept of "the use of cloud technology" as an introduction to the practical work of a computer science teacher. Appropriate training of bachelors of computer science should be carried out continuously and in stages throughout the study period. Its effectiveness depends on the level of use of the tools in the learning process. Therefore, it is necessary to develop a model of organization of students' learning based on cloud technologies. As a result of the introduction of the proposed model, students develop ICT competencies for using distributed cloud resources for training and research.

The cloud-based student learning organization model changes the traditional reproductive approach to practically oriented learning. For its design we have analyzed similar models. They usually contain motivational, cognitive, activity, productive components [39, 40, 41].

They all transform the educational process from a system that operates on externally set standards to a self-evolving system. The main components of our model are shown in figure 1.

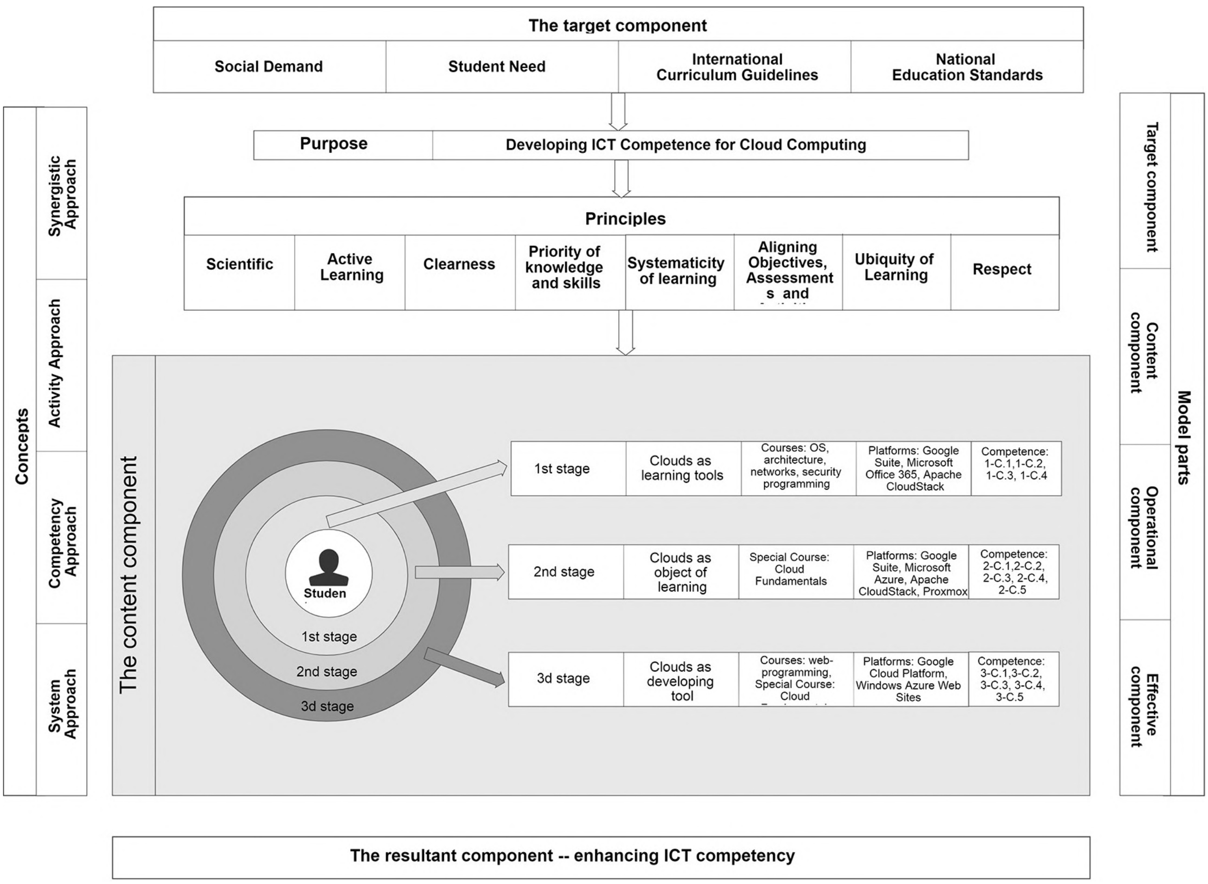

Figure 1: The model for learning cloud computing.

The target component of model provides the creation of conditions for the organization and support of joint educational and research work of students. It provides for the formation of cloud based learning environment of a university. Based on the previous analysis, we can claim that there is a social demand for a teacher who has competencies in the use of cloud technologies. Such a teacher should be able to organize the CBLE of school, to form the appropriate competence in students. In each of these three stages, we envision students using cloud computing at a different level of awareness. The purpose of this component is the goal setting of stage, on which the effectiveness of the whole process depends. The target component also determines the creation of conditions for the formation of personal capacity for future professional activity in the conditions of modern technological changes.

The purpose of training is implemented through methodological approaches such as:

- the competency approach allows to identify the content of ICT competencies in the use of cloud technologies, to improve the practical orientation of the learning process;
- the system approach allows to consider all components of the proposed model as a coherent system. A system approach requires designing the model as a set of interrelated elements. Integrative dependencies and interactions of these elements are also needed;
- the action approach focuses on the prioritization of active learning methods;
- synergistic approach considers the basic processes of student self-organization and interaction. Learning according to this approach is an unstable process. This instability complicates adaptation, cognitive operations, and overall activity.

The guiding principles of the methodology according to our model are the traditional principles of science, accessibility, continuity, systematicity and consistency, activity, clarity. Other principles of learning such as mobility, adaptability, flexibility, ubiquity are also important.

The content component of the model is aimed at developing both the key (digital, personal, social, educational) and subject competences of future computer science teachers.

At the center of the proposed model is a student. Accordingly, the competence structure defines the components by the stages of implementation. They correspond to the preparatory, activity, generalization stages of the use of cloud technologies. The study in the preparatory and activity stage should be done in the bachelor's degree. The generalization stage can be implemented as a master's program.

At the preparatory stage, cloud technology is a means of organizing educational and cognitive activity. The relevant components of subject competence are such as:

- ability to be guided by features of modern cloud technologies, to understand their functionality and to be used for basic educational tasks;
- ability to distinguish between features and characteristics of "traditional" Internet services, hosting web resources, running virtual private machines in cloud infra-structures;
- ability to determine the ways of using cloud technologies for the organization of training and research activities according to service models;
- ability to behave adequately and responsibly in a cloud environment, to demon-strate knowledge and understanding of the legal, ethical aspects of using cloud services and digital content;
- ability to actively and constantly explore new services, implement them in their activities, awareness of the role of cloud computing in the current stage of IT and education.

In the activity stage, cloud computing is the object of study. The relevant components of subject competence are such as:

- knowledge of basic concepts, deployment models and service models of cloud technologies, principles of operation and technology of server system virtualization, architecture and standards of distributed computing, and features of hard-ware and software solutions of modern data centers;
- ability to install, configure and maintain system, tool and application software of cloud platforms according to the basic service models;

- ability to evaluate and determine effective CBLE deployment decisions based on an analysis of the functional characteristics of cloud services and the needs of educational institutions;
- ability to design, deploy and integrate ready-made cloud platforms to improve the IT structure of the educational institution;
- ability to monitor, support and analyze the functioning of the CBLE.

At the generalization stage, cloud computing is a development tool for creating educational resources and learning tools. The relevant components of subject competence are as follows:

- ability to formulate requirements for quality assurance of software development for its functioning in the cloud applications;
- ability to evaluate and identify effective deployment solutions for CBLE based on a comparison of the technical and economic properties of cloud computing services, as well as for solutions based on private and hybrid cloud systems;
- ability to formulate ways to increase the efficiency of the use of cloud technologies in solving organizational educational and scientific tasks;
- ability to develop software for educational institutions in a cloud computing environment, test and debug relevant hardware and software;
- ability to project activities, work in a team to jointly solve educational and scientific tasks.

The technological component of the model defines the system of teaching methods. We consider appropriate methods of teaching cloud technologies such as:

- classrooms training (lectures, storytelling, presentations, group discussions, tutorials etc);
- interactive methods (quizzes, small group discussions, case studies, participant control, demonstrations etc);
- services, as well as for solutions based on private and hybrid cloud systems;
- e-learning (web-based training, web meetings, webinars, collaborative document preparation, work in CBLE);
- practical training methods (project, training).

In general, these methods aim at providing a blended learning methodology. Their application is possible during lectures, laboratory work, self-study trainings, individual and group consultations. We include the traditional means and components of CBLE in the training tools.

To provide group work and student feedback in each course, we use tools such as:

- emails and messengers;
- software for remote access to the objects of students in CBLE;
- module and final tests;
- Likert scale course feedback.

The resultant component of the model involves providing ubiquitous access to learning resources through standardized protocols, enhancing students' ICT competency, improving the quality of educational process organization and pedagogical research.

We consider it necessary to use public and private clouds as a teaching tool not only in the first stage, but also throughout the whole time of studying the bachelor of computer science. Such public clouds are G Suite and Microsoft Office 365. Their developers offer free subscriptions to educational institutions. Students and staff can get corporate accounts of these cloud platforms. The use of these platforms can be practiced in almost all courses of professional training of the future computer science teacher.

For example, a teacher can schedule study assignments, student work, online consultations using Calendar services. For training demonstrations, webinars can be effective cloud services such as Google Meet and Skype for Business and more.

Topical issues of using cloud technologies in training are their integration with each other and with other learning tools. Such integration should provide single authentication (Single Sign-On – SSO), content availability in various cloud services, access from mobile devices, and ability to monitor student activity.

Great technical and training capabilities are in the deployment of private academic cloud according to the IaaS model. We have deployed a similar cloud based on the Apache CloudStack platform. It combines the system resources of 4 servers. This allows you to run 20-50 virtual machines at a time. With Apache CloudStack's enhanced networking capabilities, we have integrated these computers into a large number of virtual local area networks (VLANs). To provide universal access to the virtual labs, 2 virtual private network (VPN) servers were set up. They work with different protocols. Therefore, students are able to work with these labs from any device that has Internet access. All these services have formed a cloud infrastructure that is integrated into the university's LAN. Such an academic cloud makes it possible to create "cloud laboratories". In our opinion, a cloud lab is a system where virtual ICT objects are generated through cloud computing and networking. Cloud labs are best used to teach basic computer science courses, such as computer architecture, operating systems, programming, computer networks, and more.

One of these laboratories (CL-OS) was deployed for training. Its purpose was the development of ICT competences, the education of the need for systematic updating of knowledge, the formation of project activity skills. To complete with the tasks, the students were supposed to have basic knowledge of the following disciplines: Operating Systems, Computer Architecture and Software. The main teaching methods in this training were group and project techniques. Students' educational projects were about practically important tasks, such as: recovery of destroyed data, increase of operating systems performance, error correction during loading, virus removal.

Students use G Suite and Microsoft Office 365 public clouds to discuss learning problems, create and edit shared documents (diagram, abstract, brochure, booklet, infographics). They acquire teamwork skills such as communication, teamwork and group leadership; formulation of tasks for yourself and colleagues, perform tasks in a timely manner [42].

Each of the group members was provided with a separate virtual machine. It had defects of one of the above types. Students were able to work on solving problems not only from any university computer, but also from their home PC. To train one group of students, an academic cloud provided 20–30 virtual machines (VMs).

Another cloud lab (CL-EVE-NET) was organized to study computer networks. We have integrated the Apache CloudStack and EVE-NG Community Edition platforms to deploy it. Nested Virtualization technology was used for this purpose. The EVE-NG platform makes it possible to emulate the operation of different nodes that are integrated in an internetwork. These nodes can be virtual machines running different operating systems. The integration of EVE-NG and Apache CloudStack platforms enables the use of full-featured network OS.

The integration of EVE-NG and Apache CloudStack platforms enables the use of full-featured network OS. They can be accessed via the EVE-NG platform web interface and through Telnet and VNC protocols. This lab uses both Apache CloudStack virtual networks and ENE-NG platforms. If the student configures the network connections correctly, access will also be available through the appropriate protocols.

We used the CL-EVE-NET lab to study basic computer network topics, such as: switching and bridging, network monitoring tools, basic and NAT routing; dynamic routing protocols; load-balancing Internet channel, policy base routing, data filter with firewall, network protocols and services (DHCP, ARP, DNS); virtual private network protocols [43].

This cloud lab allows you to bring together individual student networks. As a result, we get a internetwork of group. This approach ensures student collaboration and teamwork. An error with one of them can causes problems throughout the network. For the training of one group of students, an academic cloud provided the functioning of 20 "parent" VMs. They ran up to 10 nested virtual network devices (bridges, switches, routers, hosts).

The CL-ADM cloud lab has been deployed for the network administration course. In this course, we use both Windows and Linux. So, to study each topic, we create at least 2 virtual machines as servers and at least 2 VMs as clients.

The main topics of the course are:

- network administration of Windows and Linux servers (local users and groups, filesystems security, network shares, remote administration);
- domain administration (Active Directory, Samba, NIS);
- server application administration (Apache, ProFTPd, IIS, Postfix, Dovecot SQUID).

To train one group of students, an academic cloud provided 30–40 virtual machines. Training at the activity and generalization stages is carried out according to the special program "Cloud Technologies Fundamentals".

The course involves the study of: publicly available cloud platforms by recognized software development vendors (Google Inc., Microsoft), and open source software as the foundation for enterprise cloud.

The main topics of the special course are:

- public cloud platforms (G Suite and Microsoft Office 365);
- cloud platforms for private clouds (Apache CloudStack, Proxmox).

We used to study the G Suite and Microsoft Office 365 public platforms in the form of a Cloud Services to Every School project [44]. The objectives of the project were to design and deploy cloud services for secondary schools. The basics of the project concept were: absence of material costs for deployment and support of cloud services, voluntary nature of participation in the project. In collaboration with computer science teachers, students determined which services needed to be configured or migrated to the cloud. The problems of maintenance and support required a lot of time. Teachers had questions about administering, configuring, monitoring cloud services. We solved such problems by organizing face-to-face and distance seminars, workshops, also through the involvement of students in the support of deployed systems.

The results of the "Cloud Services to Every School" project is in line with the indicators of a cloud-based learning environment. They are: quality and accessibility of learning, adaptability, interactivity and mobility of ICT tools, unification of the school's IT infrastructure, ensuring its security.

We propose to study private clouds on the example of open platforms. We suggest exploring private clouds as an example of open platforms. Their advantages are open source, freeware, English documentation, the ability to deploy advanced cloud infrastructures. However, such platforms are usually not supported by the developer. Therefore, teaching students with such platforms often requires them to look for solutions to various problems. This approach requires modern hardware. Private clouds require servers that perform different functions. For deployment by students of such clouds it is necessary to use the group method. It is a division of tasks. Students can perform tasks together or individually such as:

- configuring the database server;
- cloud platform setup;
- installing hypervisors;
- creating virtual computers;
- distribution of system resources.

In the future, students change roles. Since at our university the special course "Fundamentals of Cloud Technologies" is studied in the master's program, we consider it appropriate to use a research approach. It is that the teacher formulates detailed technical requirements for the cloud. Students research and customize platforms to meet these requirements. The results of such research can be summarized by the method of comparative analysis. For example, one platform may have better performance for the production platform and another platform will perform more effectively as part of the CBLE.

Important in the ICT competency of the future computer science teacher is the possession of software development tools. Cloud services should be at the forefront of creating students' own educational information resources. The third stage of our model is dedicated to this task.Training can be based on this platform leader in software and cloud.

Microsoft has developed a Windows Azure Web Sites product that enables students to create new and host existing web applications in a secure cloud storage. Windows Azure Web Sites implements a Platform as a Service (PaaS) model. Therefore, students will be able to fully focus on the programming and direct development of their cloud projects.

Google also offers a similar Google Cloud Platform (GLP) cloud service. It allows you to create, test and deploy your own applications in the cloud. Students can learn how to create state-of-the-art web applications and mobile applications on the open Google App Engine cloud platform. It is a managed platform that completely abstracts the cloud infrastructure, which helps to focus training on development tasks.

Deployment of cloud laboratories is also appropriate for a full study of these systems. Unfortunately, Google has not yet provided academic grants to use GLP for Ukrainian universities. However, students are free to use their own accounts for one year. A similar situation with Microsoft products. It is necessary to get a Microsoft Azure Education Grant for effective learning.

We propose to use a comprehensive approach and project methodology in the process of studying these tools. The main requirements of applying the project methodology at this stage are as follows:

- identifying the main problem that the created project should solve;
- requirement for student creativity in project development;
- no restrictions on the tools and their functionality;
- the value of the expected result, that is, a cloud-based application must be developed and deployed;
- organization of joint activities of students;
- identification of pre-formed competencies for project creation;
- the project's focus on modern cloud and web technologies.

The third (generalization) stage of our methodology consists of several logical parts. They combine a relatively small amount of theoretical material. It's a good idea for a teacher to start learning about the Google Cloud Platform (GCP). The practical part involves setting up the environment and creating a project, configuring a cloud database. The next task is to log in and log in. After that, students should focus on project architecture and development of core functionality.

We invite students to develop a contact manager. Its main functionality is to enable an authorized user to create, view, edit and delete records. It also has the option of sending e-mails to selected contacts. This basic functionality is present in almost every modern web application. Students can use GCP cloud products such as Google App Engine standard environment, Google Cloud SQL, Google Cloud Datastore, Google Cloud Storage and Google Cloud Pub to develop it.

Application development in the Google Cloud Platform facilitates group form organization. The teacher can add new project participants and assign them specific roles to determine the degree of access. In this project, the teacher demonstrates GLP capabilities based on such programming tools as PHP and Node.js. Important issues for cloud-based application development are understanding:

- basic functionality of PHP and Node.js;
- basics of a modular, file and batch system;
- file management;
- use of the postal service;
- work with the MySQL database.

The next step is to introduce students to the Google Cloud Platform environment, the basics of App Engine, and the application deployment process. It is a good idea for the teacher to organize the development of the project in a private university cloud and then deploy it into a public cloud. It is also possible to develop the project only in a cloud environment. Both approaches include steps to develop a web application that will allow users to submit requests to the server.

After completing these tasks, students develop their own ICT competencies such as:

- creating a GCP project based on App Engine;
- writing a web server on Node.js;
- deploy code on App Engine and view the web application in real time;
- adding updates to an already deployed service.

After creating this application, students move on to expand its functionality through other GLP services. Further practical work focuses on developing students' own cloud applications. These can be an online study log, e-library, video hosting service, photo gallery etc. Their students perform in small groups of 2-3 people. They can offer their own themes for development. Upon completion, students present projects and share their experiences and achievements.

4. Testing the effectiveness of the author's methodology

We conducted a pedagogical experiment to verify the developed methodology. The study was conducted during 2016–2020. We investigated the development of ICT competence under the conditions of implementation of the proposed model. The aim of the study was to identify changes in the levels of ICT competence of students. According to the research of many scientists this competence contains basic theoretical knowledge, methods of practical activity, motivational relations and the ability to apply cloud technologies in the future [45, 46, 47]. They almost completely correspond to the structure of our model of application of cloud technologies. Let's look at each of these components.

The motivational (target) component contains motives, goals, needs for professional training, self-improvement, self-development by means of cloud technologies. It stimulates creativity in the professional activities of a computer science teacher. Accordingly, the student must develop a need for constant updating of his (her) own knowledge. The motivational component contains the motives for teaching, the focus on the development of students' personalities.

The content component of ICT competence of future computer science teachers provides free mastery of skills in working with digital objects. The level of development of the content component is determined by the completeness, depth, system of knowledge of computer and related sciences. It requires knowledge of the principles of cloud computing, its use for the design and development of educational resources. Knowledge of the security threats and limitations of these tools is also required.

Activity (operational) component involves the development of skills (including soft-skills) for the application of cloud technologies in future professional activities. These include the ability to establish interpersonal relationships in the educational environment, to choose the right style of communication in different situations. Basically, this component requires the skills and experience needed by future computer science teachers to solve problems using cloud technology. Advanced development of this component requires mastering and forming the readiness of future computer science teachers to develop and implement cloud computing in the educational process. The formation of appropriate skills should be determined by the professional needs of future computer science teachers.

The reflective (effective) component of ICT competence is determined by the attitude of students to their practical activities. It includes self-control, self-esteem, understanding of their own role in the team. Important for this component are the evaluation of the results of their activities, understanding the responsibility for its results, professional self-realization through the means of cloud technologies.

The study had ascertaining and search stages. The ascertaining stage corresponded to the first and second stages of the author's model. The study was conducted in the bachelor's course "Computer Networks". Since most of the components of the author's model are implemented at the generalization stage, we decided that the search stage should be performed in the process of learning a special course " Cloud Technologies Fundamentals".

At each stage of the experiment, the following data were processed:

- results of the questionnaire like course feedback, as data for studying the target component;
- grades for all course tests as data of the content component of the model;
- grades received by students for laboratory work as data of the operational component;
- assessments for a competency task as data of the effective component.

For statistical processing of these data, we used the methodology developed by Kuzminska [48, 49, 50, 51]. To ensure a sufficient sample size, we had to process the data for 4 years. We studied the changes and tried to identify differences in the data of each of the components of ICT competence. To ensure the homogeneity of the groups at both stages, the results of questionnaires and assessments of the same students were processed. There were a total of 196 students in these study periods. All data of the ascertainment and search stage are available by the following link https://drive.google.com/file/d/1n-lPQI-eGFMJiuwq_jI7BaWoM3aTUNK0.

Assessment in each of the courses was on a 100-point scale with a distribution such as:

- maximum 40 points for the test tasks of the course (content component);
- maximum 40 points for laboratory work (operational component);
- maximum 20 points for the performance of the competence task (effective component).

In addition to 20 points, the student could receive for answering the questionnaire, which gave an answer to the feedback about the course. To choose a statistical method, we took into account the following facts:

1. The data are quantitative; therefore, we can use numerical scales.
2. The data may not correspond to the normal distribution. Therefore, it is necessary to check this for each of the components of ICT competence at each stage of the study.
3. Samples of each year of study are independent.
4. There are 4 groups for comparison.

We performed data processing using the R language. First, we checked the data distribution of each component is normal for the ascertaining stage.

```
lillie.test(AscertainingStageData$Target)
#Lilliefors (Kolmogorov-Smirnov) normality test
#data:  AscertainingStageData$Target
#D = 0.074284, p-value = 0.01045
lillie.test(AscertainingStageData$Content)
#Lilliefors (Kolmogorov-Smirnov) normality test
#data:  AscertainingStageData$Content
#D = 0.056802, p-value = 0.1276
lillie.test(AscertainingStageData$Operational)
#Lilliefors (Kolmogorov-Smirnov) normality test
#data:  AscertainingStageData$Operational
#D = 0.055232, p-value = 0.1531
lillie.test(AscertainingStageData$Effective)
#Lilliefors (Kolmogorov-Smirnov) normality test
#data:  AscertainingStageData$Effective
#D = 0.085305, p-value = 0.001434
```

As can be seen from the code listing above, the data distributions of the content and the operational components are normal, and the target and effective are not. Therefore, a more powerful one-way ANOVA method for independent groups can be used to process the first two cases. Another pair of components should be processed using a non-parametric Kruskal–Wallis one-way analysis of variance. These methods allow to check whether the studied groups are homogeneous.

Additionally, for the ANOVA method, the homogeneity of variances in each distribution should be checked. We performed this using Leveneś test for homogeneity.

```
leveneTest(AscertainingStageData$Content\
~AscertainingStageData$Years,AscertainingStageData,center=mean)
#Levene's Test for Homogeneity of Variance (center = mean)
#       Df F value Pr(>F)
#group   3  0.2084 0.8905
#       192
leveneTest(AscertainingStageData$Operational\
~AscertainingStageData$Years,AscertainingStageData,center=mean)
#Levene's Test for Homogeneity of Variance (center = mean)
#       Df F value Pr(>F)
#group   3  1.6235 0.1853
#       192
```

As can be seen from the listing F value = 0.8905 and F value = 1.6235 (for content and operational components in accordance). These values are smaller for the critical value $F_{0.05}(3; 192) = 8.53$. The corresponding p-values (Pr = 0.8905 and Pr = 0.1853) are greater than the significance level ($\alpha = 0.05$). This is a reason to reject the null hypothesis about the difference of variances in the samples. Therefore, the ANOVA method can be used for the content and activity components.

Then the null and alternative hypotheses are as follows:

- H0 – there are differences between the groups at the ascertaining stage;
- H1 – there are no differences between the groups at the ascertaining stage;

The following code contains a test of these hypotheses.

```
summary(aov(Content~Years,data=AscertainingStageData))
#             Df Sum Sq Mean Sq F value Pr(>F)
#Years         3     57   18.96   0.822  0.483
#Residuals   192   4431   23.08
summary(aov(Operational~Years,data=AscertainingStageData))
#             Df Sum Sq Mean Sq F value Pr(>F)
#Years         3     57   19.04   0.751  0.523
#Residuals   192   4870   25.36
```

Thus, for both components we can reject the zero and accept the alternative hypothesis. Similar hypotheses can be formulated for the target and effective components. Here is a test of group homogeneity for these components using the Kruskal-Wallis one-way analysis of variance.

```
kruskal.test(Target~Years, data = AscertainingStageData)
#Kruskal-Wallis rank sum test
#data:  Target by Years
#Kruskal-Wallis chi-squared = 6.3968, df = 3, p-value = 0.09382
kruskal.test(Effective~Years, data = AscertainingStageData)
#Kruskal-Wallis rank sum test
#data:  Target by Effective
#Kruskal-Wallis chi-squared = 0.55391, df = 3, p-value = 0.9069
```

The test showed that we can accept an alternative hypothesis about the homogeneity of groups. The task of the search phase of the study was to identify differences between groups during the 2017-2020 years of the study. During this period, in each academic year, we introduced the some technical and methodological components of the mod-el such as:

- 2016–2017: deployed CL-OS laboratory;
- 2017–2018: the project "Cloud services in each school" was implemented;

- 2018–2019: deployed CL-EVE-NET and CL-ADM laboratories;
- 2019–2020: Coursera courses on Google Cloud Platform are included in the special course "Cloud Technologies Fundamentals".

Similar to the ascertainment stage, we analysed the results of the questionnaire, grades for tests, laboratory works and competence task.

The questionnaire for diagnosing the level of the motivational component contained 20 questions. For each positive answer to the questionnaire, the student received one point. Points for completing the questionnaire, grades from the course were obtained by students in a special course "Cloud Technology Fundamentals" in 2016-2020. Here are the questions.

1. I understand the importance of cloud technologies for the organization of educational activities.
2. I understand the importance of cloud technologies for the organization of design and research activities of students.
3. I understand the importance of cloud technologies for the organization of extracurricular activities of students.
4. I am aware that cloud technologies expand the opportunities for the development of students' ICT competence
5. I follow the emergence of new cloud services for education.
6. I am watching the emergence of new platforms for the deployment of private clouds.
7. I have studied cloud platforms in MOOCs.
8. I have the skills to develop cloud applications.
9. I can develop separate cloud services for CBLE school.
10. I know the benefits of cloud services as a means of supporting teacher self-development and self-improvement.
11. I understand that the use of cloud services has a positive impact on the quality of teaching and diversifies forms of learning.
12. I try to monitor the emergence of new resources and tools for cloud technology to improve their competence.
13. I realize that it is necessary for teachers to implement and disseminate new ideas about the use of cloud technologies.
14. I am aware of the advantages of cloud technologies and modern means of communication for cooperation between educational institutions.
15. I am aware of the benefits of cloud technology to reduce the cost of education.
16. I am interested in using cloud technologies to improve communication and increase the competitiveness of educational institutions.
17. I adhere to legal and ethical standards when using cloud services and digital content.
18. I participated in joint projects to develop an effective educational environment.
19. I have deployed cloud services for educational institutions.
20. I performed support of CBLE of school.

Diagnosis of the level of the analytical component of ICT competence of future computer science teachers was investigated by testing the ability to use the acquired knowledge and skills in non-standard situations. Students had to demonstrate the ability to perform reflective analysis and correction of their digital activities. We offered undergraduates to perform a competency task. They had to develop a long-term plan for the development of CBLE educational institution. The plan implementation algorithm was to contain a detailed description of each stage of CBLE deployment and use in the school.

1. CBLE design:
    - analysis of the state of the school's digital environment;

- studying the specifics of the activities of teachers and students and determining their needs for the use of cloud services;
- determining the functionality of cloud services;
- identification of subjects for which it is not yet possible to implement the necessary functionality;
- technical audit of the digital environment of damage, including hardware, software, personal devices, availability of Internet access;
- finding out the financial capabilities of the educational institution.

2. Recommendations for implementation
   - informing teachers, students, parents about the structure and possibilities of using CBLE;
   - designing a security policy for the use of cloud services and notifying it to all participants in the educational process;
   - development and implementation of an algorithm for deploying cloud platforms;
   - technical and pedagogical support of activities in CBLE;
   - training of school staff, informing the administration about the development of digital technologies.
3. Development prospects
   - determining the scalability of the CBLE;
   - development of an action plan in case of breach of confidentiality of personal data;
   - support for modern standards, protocols, rules for updating all components of the environment;
   - participation in national and international educational projects.

Again, let's check the normality of the distribution of points obtained by students at the search stage. Here are the results of the Kolmogorov-Smirnov test:

- target component: D = 0.070342, p-value = 0.01958;
- content component: D = 0.060965, p-value = 0.07329;
- activity component: D = 0.062046, p-value = 0.06374;
- effective component: D = 0.10837, p-value = 0.000007515.

P-values for motivational and effective components again do not correspond to the normal distribution. P-values for the content and activity components are close to the critical value of 0.05, but still exceed it. Therefore, we will consider the obtained distributions to be normal. Let us check the homogeneity of their dispersions. Here is the result of running leveneTest:

- content component: F value= 0.9305, Pr(>F)= 0.427;
- activity component: F value= 0.5496, Pr(>F)= 0.649

Therefore, we can apply the One-way ANOVA test for the content and operational components. Here are the results of calling the corresponding function.

```
summary(aov(Content~Years,data=ResearchingStageData))
#              Df Sum Sq Mean Sq F value Pr(>F)
#Years          3    378   126.0   3.612 0.0143 *
#Residuals    192   6701    34.9
#Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

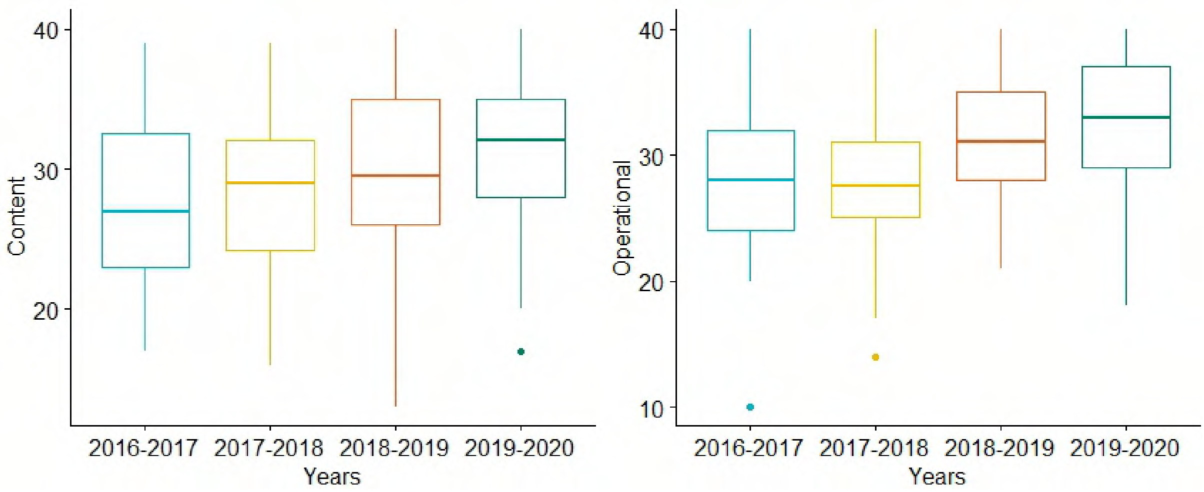

Figure 2: Range diagrams of average values of content and operational components

As can be seen from the listing, we have to accept the alternative hypothesis in both cases. That is, there are differences between groups. Figure 2 shows quantile scale diagrams. The dots on the chart show the emissions. In our case, such emissions are low grades of students who have very low grades from the course.

We can assume that the factor that caused these changes is the introduction of the author's methodology. To determinate a set of confidence intervals for the differences between the means of the factor's levels with the specified probability of coverage we have used Tukey's 'Honest Significant Difference' method for both components.

```
TukeyHSD(aov(Content~Years,data=ResearchingStageData))
#$Years                    diff        lwr      upr     p adj
#2017-2018-2016-2017 0.9925994 -2.1827991 4.167998 0.8496254
#2018-2019-2016-2017 2.3033885 -0.7508257 5.357603 0.2090704
#2019-2020-2016-2017 3.7281806  0.6022937 6.854068 0.0121774
#2018-2019-2017-2018 1.3107890 -1.7611233 4.382701 0.6863632
#2019-2020-2017-2018 2.7355812 -0.4076003 5.878763 0.1122965
#2019-2020-2018-2019 1.4247921 -1.5959128 4.445497 0.6133838
```

For the content component, the differences between the values of the 2016–2017 and 2019–2020 academic years are statistically significant changes.

```
TukeyHSD(aov(Operational~Years, data=ResearchingStageData))
#$Years                    diff        lwr      upr     p adj
#2017-2018-2016-2017 0.06336725 -2.9224371 3.049172 0.9999401
#2018-2019-2016-2017 3.45547675  0.5836212 6.327332 0.0111944
#2019-2020-2016-2017 4.33000434  1.3907555 7.269253 0.0010348
#2018-2019-2017-2018 3.39210950  0.5036125 6.280606 0.0140729
#2019-2020-2017-2018 4.26663709  1.3111262 7.222148 0.0013706
#2019-2020-2018-2019 0.87452759 -1.9658195 3.714875 0.8552859
```

From the above listing, we can conclude that almost all components of the model had the skills to create, deploy and use cloud technologies.

To assess the development of the target component, we use the Kruskal-Wallis test. Here are its results:

- Target by Years Kruskal-Wallis chi-squared = 7.0967, df = 3, p-value = 0.06888;

From the obtained test data, we can still accept the null hypothesis that there are no statistically significant differences between the groups. Therefore, we cannot draw a reasonable conclusion about the impact of our model on the development of the motivational component of ICT competence.

For the reflex component, the results of the Kruskal-Wallis test are as follows:

- Effective by Years Kruskal-Wallis chi-squared = 18.66, df = 3, p-value = 0.0003213;

In this case, we accept an alternative hypothesis about the existence of differences between groups of students. In order to make multiple comparisons between groups, possibly with a correction to control the experiment wise error rate we have performed Dunn's Kruskal-Wallis test. Here are its results:

```
PT = dunnTest(Effective~Years,data = ResearchingStageData)
PT
#          Comparison           Z      P.unadj       P.adj
#1 2016-2017 - 2017-2018  0.08638957 0.9311567356 0.931156736
#2 2016-2017 - 2018-2019 -1.70307343 0.0885543273 0.177108655
#3 2017-2018 - 2018-2019 -1.78256141 0.0746577266 0.223973180
#4 2016-2017 - 2019-2020 -3.66052102 0.0002517029 0.001258514
#5 2017-2018 - 2019-2020 -3.72765494 0.0001932697 0.001159618
#6 2018-2019 - 2019-2020 -2.06601565 0.0388270019 0.155308008
```

The results of this test show that there are differences between 2016-2017 – 2019-2020 and 2016-2017 – 2019-2020 pairs of years. Therefore, we can conclude that participation in a real project had a positive impact on students' integrated under-standing of the role of cloud technologies in the digitalization of the school learning process.

5. Conclusion

The use of cloud computing in the training of future computer science teachers is a relevant and important issue that requires further research. The training of cloud computing should be systematic, gradual, and continuous throughout the student's study period. We have proposed a model of teaching and learning cloud computing for future computer science teachers, which consists of four components: target, content, operational, and effective. The content component is implemented in three stages:

1. Cloud technology as a means of education.
2. Cloud computing as an object of study.
3. Cloud computing as a development tool.

The first and second stages should be conducted in the bachelor's degree, while the third stage can be offered as a master's program.

The current level of cloud computing development makes the project method a suitable and effective way of teaching and learning cloud computing. Participation in the proposed projects helps students develop their skills of independent and responsible work with cloud technologies, as well as their awareness of the role and potential of cloud computing.

Our model combines face-to-face and online learning, which allows teachers to leverage the advantages of the cloud-based learning environment (CBLE). The CBLE is based on a hybrid cloud model that integrates public and private cloud platforms, as well as cloud and traditional learning tools.

According to the results of the experiment, our hypothesis of a positive impact of the designed CBLE on the development of ICT competence of future computer science teachers was confirmed. The experiment showed significant improvements in the students' integrated understanding and practical skills of cloud computing.

The qualitative changes in the dynamics of development of ICT competence components of students using our model confirmed the effectiveness of our methodology.

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Teaching statistics to future programmers using real data sets and R programming language

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Abstract

This paper addresses the problem of teaching statistics to future programmers. It argues that the theoretical content of teaching statistics needs to be updated and oriented towards the practical field, even at the higher education level. It suggests that the teaching of statistics to students should move from theoretical methods to practical solutions of applied problems and emphasize the analysis and interpretation of results rather than the statistical calculations. The paper proposes a system of tasks based on real data sets obtained from statistical research as a way of improving the learning of statistics for future programmers. It shows that such tasks can increase the students' motivation compared to synthetic examples, which are commonly used in statistics courses. The paper also reviews the software tools for statistical data analysis and identifies their features and advantages for the learning process. It recommends using R, a specialized programming language, as the main tool for teaching statistics.

Keywords

statistics education, future programmers, real data sets, R programming language, applied problems

1. Introduction

The rapid growth of information in the modern world poses a challenge for the statistical education of society. Statistics is an essential component of the educational programs for training specialists in the field of IT [1, 2]. However, teaching statistics to students often encounters various problems, such as: different levels of prior knowledge, low level of motivation, lack of understanding of the relevance and applicability of statistics for their future profession [3].

The discipline of statistics has been undergoing significant changes and developments in recent years. Cox [4], Moore [5], Smith and Staetsky [6] raise many questions about the need to improve the objectives, content, methods and forms of teaching statistics.

Many researchers have investigated the issues and challenges of teaching statistics. They have provided recommendations for teaching statistics in different types of educational institutions [7, 8, 9, 10, 11, 12, 13]. Some of them have suggested moving from the theoretical learning to the practical application of statistical methods [10, 14].

Nicholl [15] notes that the theoretical content of teaching statistics has expanded significantly over the past 50 years, but this process has been uncoordinated, by adding new concepts without removing old ones. As a result, the content of teaching statistics has become overloaded with theoretical concepts that do not enhance the students' motivation and interest in learning statistics. Rumsey [16], Gal and Garfield [17] draw attention to the problems of teaching statistics and propose to change the paradigm of teaching and focus on the practical field, even at the higher education level.

Education is seen as an investment in human capital and production. The World Economic Forum predicts that the global demand for statistical data analysts will increase by almost six times in the next

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five years.

According to the Modis survey [18], 97.44% of respondents (representatives of banks and industry) consider data analysis as a promising skill for success in sales and marketing. However, they are more interested in interpreting the data than in performing the calculations. 42% of respondents complain about the shortage of qualified professionals who have skills in statistical data analysis in the labor market. 55% of respondents say that it is difficult to find specialists who can calculate and interpret the results.

Every day, large amounts of various data are generated and accumulated in the world [19]. Therefore, the labor market demand for data analysts and data scientists is constantly growing. Varian [20] notes that data analyst will become one of the most popular professions in the future.

Therefore, improving the education of students in statistics requires moving from the theoretical methods to the practical solutions of applied problems and shifting the emphasis from the statistical calculations to the analysis and interpretation of results.

To prepare an intellectually active, knowledgeable and skillful specialist, education needs to move from the reproductive to the innovative learning. Innovative learning is a creative combination of the traditional and new teaching methods, tailored to each discipline, based on its theoretical content and practical orientation [21]. Moreover, it should be considered that teaching students is not only about developing certain professional competencies, but also about aligning them with the current modern requirements [22]. It means that the future specialists should be able to express their thoughts and concepts verbally, understand the language of symbols, signs and schemes. This is not just the ability to think creatively, but also the ability to make original decisions and actions.

To organize innovative teaching of statistics in accordance with modern requirements, it is advisable to use special software tools for statistical data analysis. However, there are also specialized programming languages and environments that can be used to analyze data, interpret results and prepare conclusions and reports in various formats quickly and efficiently.

Therefore, there is a contradiction between the traditional approaches to teaching statistics and the society's expectations for the level of training of modern IT specialists in the field of statistical data analysis, as well as between the theoretical orientation of the content of statistics teaching and the need to train a specialist with applied tools and methods of statistical data analysis.

The aim of this paper is to justify the use of R programming language as a teaching method for learning statistics.

2. Results

The following main methods were used in the research process: content analysis of scientific and methodical literature, generalization and systematization to clarify the state of the problem development; questionnaire of those getting higher education and initial statistical processing of the obtained results to clarify the current state of the researched problem; generalization of theoretical and practical data to justify the introduction of innovative approaches to the study of statistics by students based on the use of programming language R.

The process of teaching statistics to the students is associated with certain difficulties: the study material in this course contains a large number of definitions and formulas. At the same time, students need not only to reproduce them, but also to understand the meaning and be able to apply in practice. However, with the traditional organization of the educational process, practical tasks are far from the real economic, social and other processes that occur in real life. The analyzed data are generalized and do not allow to fully form students' understanding of the need and expediency of studying this discipline and the opportunity to implement the acquired competencies in their further professional activities.

Therefore, most students learn statistics in fragments, and do not form systemic knowledge as a result. In addition, mainly verbal presentation of information increases fatigue, resulting reducing productivity of the learning process [23].

The number of statistically educated people is decreasing. It is difficult for potential employers to find a specialist who will be able to perform statistical calculations without prior training and explanation. Therefore, there is a need to improve the content of teaching this discipline through the introduction of practical tasks.

Improving the content of the statistics course requires the introduction of changes in the methods and means of its teaching using innovative technologies.

Scientific innovations that promote scientific progress cover all areas of knowledge. There are socio-economic, organizational and managerial, technical and technological innovations. One of the types of social innovations is pedagogical innovation.

Pedagogical innovation is an innovation in the field of pedagogy, purposeful progressive changes that make stable elements (innovations) in the educational environment that improve the characteristics of both – its individual components and the educational system on the whole [24].

Pedagogical innovations can be carried out both with the application of the educational system's own resources (intensive way of development) and with the involvement of additional capacities (investments) – new means, equipment, technologies, capital investments, etc. (extensive way of development).

Kazakov [25] notes that the combination of intensive and extensive ways of pedagogical systems development allows to carry out so-called "integrated innovations", which are built at the junction of various, multilevel pedagogical subsystems and their components.

The main ways and objects of innovative transformations in the teaching of statistics are:

- making concepts and strategies for the development of statistical education [26];
- updating the content of statistics training;
- change and development of new learning technologies;
- improving the training of IT specialists in the field of statistical data analysis;
- designing new models of the educational process for teaching statistics;
- improving the monitoring of the educational process and student learning;
- new generation electronic teaching aids development.

Innovation can take place at different levels. The highest level includes innovations that affect the entire pedagogical system.

Kulinenko [27] notes that while organizing the innovation, it should be considered that:

- innovative ideas must be clear, convincing and adequate to the real educational needs of man and society, they must be transformed into specific goals, objectives and technologies;
- innovation activity should be morally and materially stimulated, legal support of innovation activity is necessary;
- not only results are important in pedagogical activity, but also ways, means, methods of their achievement.

The current problems of teaching statistics in modern higher educational institutions include the review of experience associated with the intensification of learning. One of the main teacher's tasks is to teach students to obtain the necessary information independently, to teach them to consciously process the obtained information [28]. In order for them to be able to study the teaching materials on their own, the materials need to be designed primarily for students and not for teachers.

Possibilities of "Statistics" discipline for experts in the field of IT consists first of all of that knowing mathematical language and modeling that will allow the student to be better guided in forecasting of economic, social, technical and other processes; secondly, that statistics by its internal nature has rich opportunities for the formation of students algorithmic thinking.

Future IT professionals must not only know the theoretical foundations, but also be able to apply the means of automating statistical analysis. Such tools include specialized statistical software packages and programming languages.

Statistical packages on the basis of functionality can be divided into 3 main groups.

1. Universal statistical packages Statistica, SPSS, Statgraphics, STATA, Stadia, SYSTAT, S-PLUS and MS Excel. These packages are not targeted at a specific subject area and can be used to analyze data from different industries. Typically, they offer a wide range of statistical methods and have a relatively simple interface.
   It is recommended to work with such packages for starter users who have only basic knowledge in the field of statistics, as well as experienced users in the initial stages of working with data, when statistical methods that will be used to address a particular issue are not clearly defined yet. The versatility of the universal package allows holding a pilot analysis of different data types using a wide range of statistical methods. The vast majority of existing universal packages has much common functionality and is similar in the composition of the built-in statistical procedures.
2. Professional statistical packages such as SAS or BMDP. Professional packages, in the contrast to the universal ones, allow you to work with extremely large amounts of data, apply highly specialized methods of analysis and create your own data processing system. As a rule, such packages are complex and should not be used in the educational process.
3. Specialized statistical packages BioStat, Datastream, Datascope, etc. were designed for statistical analysis in specific areas of activity, which use special methods of statistical analysis, usually not presented in the universal packages.

Specialized packages allow analysis using a limited number of specialized statistical methods or are used in a specialized subject area. As a rule, such statistical packages are handled by specialists who are well acquainted with data analysis methods in the field to which the package is focused. For example, the BioStat statistical package was created to analyze data in the field of biology and medicine.

Most of the existing statistical packages have a flexible modular structure that can be supplemented and expanded owing to the custom modules that are optionally purchased or freely available on the Internet. Such flexibility allows you to adapt packages to the needs of a particular user.

Statistical packages are just the tools for an experienced professional. If the specialist does not have sufficient knowledge and competencies, then, even the most advanced software product will not allow holding quality data analysis. However, the wrong software, which does not contain the required set of statistical procedures, can make the work of even an experienced specialist more difficult.

Therefore, during the training of IT specialists it is necessary to acquaint those who get higher education with the available statistical packages and their characteristics, but the application of specialized programming languages is closer and more understandable for the students while conducting statistical data analysis.

For statistical data analysis it is possible and appropriate to use R and Python programming languages.

We will consider the features of the programming language R. The language R is a powerful high-level object-oriented programming language and environment for statistical calculations and visualization of source and calculation data, which allows you to solve many problems in the field of data processing. It's a free open source program under GNU GPL designed to run common operating systems (Windows, macOS, Linux).

Tens of thousands of specialized modules and utilities have been developed for this language. One of the most important features of the programming language R is the efficient implementation of vector operations, which allows the application of compact notation while processing large amounts of data. All this makes R an effective tool for obtaining useful information from large amounts of various statistics, including Big Data.

The R language is a convenient and effective tool for teaching statistical analysis, data processing and visualization.

It is also possible to use the Python programming language in the field of data analysis and interactive research calculations with results visualization. Python is an open source object-oriented programming language. The relatively recent advent of improved libraries for Python (primarily pandas) has made it a serious competitor to the R language for statistical data analysis. Combining with the benefits of Python as a universal programming language makes it an excellent choice for creating data processing applications.

So, the use of a specialized programming language as a learning tool contributes to the development of statistical data analysis skills as well as the development of algorithmic thinking of future IT professionals.

In order to study the relevance of the problem of scientific research, a ascertaining experiment was conducted among students of IT specialties. The issues that allow finding out the opinion of higher education students on the problem of improving the methods of teaching statistics to future IT professionals were studied.

The results of the ascertaining experiment are presented in percentages and indicate the number of positive answers to the questions. The survey was organized using Google Forms. 83 students majoring in 015 Professional Education (Digital Technology) and 015 Professional Education (Computer Technology) took part in ascertaining experiment.

2.1. Declared interest of students in studying the course of statistics

In this block students were asked two questions. You can see the results of the answers to the first question of the survey in figure 1. The analysis of answers allows establishing the level of awareness of students in the demand for specialists in the labor market who know how to analyze data.

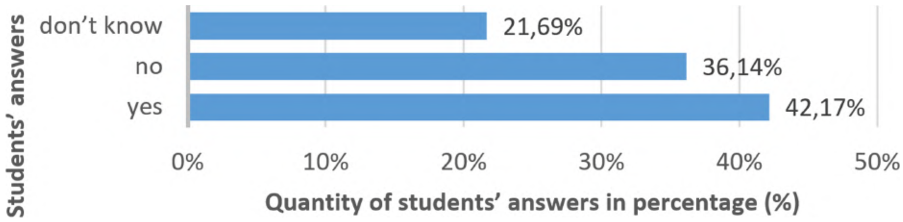

Figure 1: Results of answers to the question regarding students' awareness in the demand for the specialists on data analysis in the labor market.

Analysis of students' answers allows us to conclude that the majority of respondents, 42.17% believe that a data analysis specialist is in demand in the labor market. This confirms the relevance and need to study the course of statistics for IT professionals.

The second question clarified which specialties in data analysis students consider the most relevant today. The results of the student survey are shown in figure 2.

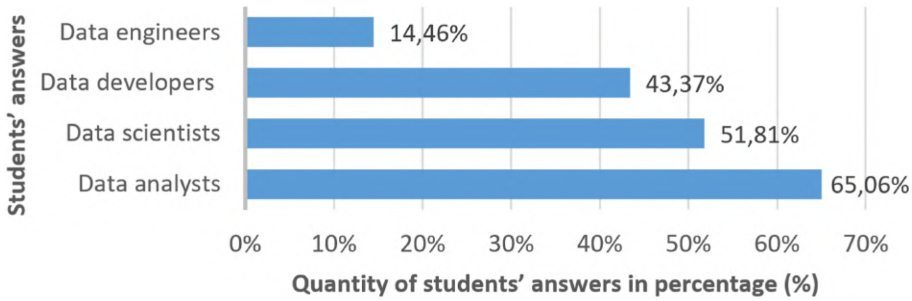

Figure 2: The results of questionnaire regarding students' awareness about modern professions on data analysis in the labor market.

The most famous profession among the future students programmers is the profession of data analysts (65.06%), in second place is the profession of data scientists (51.81%). These professions are known to more than 50% of students, which indicates their awareness and interest in this field.

So, based on the results of studying the answers to the questions of this block, we can draw the following conclusion. Training statistics of future IT professionals is relevant, because students are aware of the existence of professions in the field of data analysis and believe that they will need statistics in future professional activities.

2.2. Students' opinion about the need to fill the content with tasks of an applied nature

Students were asked to answer open-ended questions: "Which subject area data analysis you are interested conducting in?" The students' answers showed that the most popular data for processing are data from sociology, medicine, engineering, economics and biology.

Also, the idea of what data students are interested in working with in practice was studied. The results of answers to the questions are shown in figure 3.

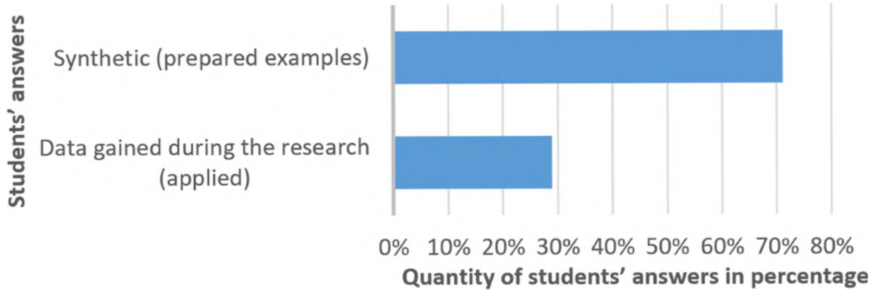

Figure 3: Students' opinion on data origin for practical tasks.

Among the surveyed respondents, 71.08% believe that data obtained as a result of practical research and having an applied nature are most attractive for them. This indicates the need to develop practical and laboratory work based on real data obtained from statistical studies.

2.3. Students' interest in using programming languages and software for statistical data analysis

The purpose of the third block of questions was to study the opinion of respondents about the need and feasibility of using software and programming languages for statistical data analysis.

Students were asked the following questions: "Do you know programming languages with which it is possible to perform statistical data analysis (enter)?", "Which software product interface is more user friendly for you?", "Are you more interested in data analysis using special software or using a programming language?"

According to the first question, the opinions of the respondents were divided as follows: 55.42% indicated the programming language R, 28.92% indicated the Python programming language. Programming languages such as C++ (9.64%) and Java (6.02%) were also indicated (figure 4).

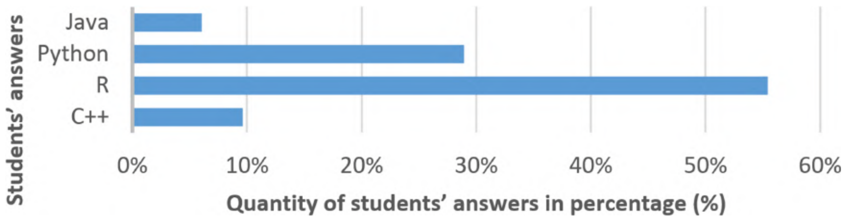

Figure 4: Respondents' answers to the question on convenience of program packages interface.

The obtained results allow us to state that the R language is the best known as a mean of statistical data analysis. So, we will use this programming language to solve application problems.

In choosing the convenience of the software package interface, respondents preferred MS Excel (56.63%), followed by Statistica software package (28.92%), followed by SPSS (14.46%) (figure 5).

So, the students will be asked to use MS Excel and Statistica for practical calculations.

According to the results of students' answers to the third question of this block, the programming language (57.83%) was chosen by the students as the main tool for organizing the training of statistical data analysis (figure 6).

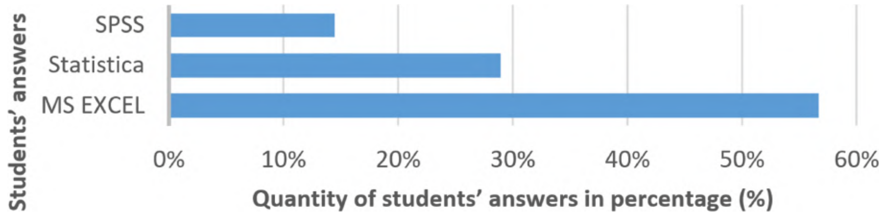

Figure 5: Choosing program packages for statistical data analysis.

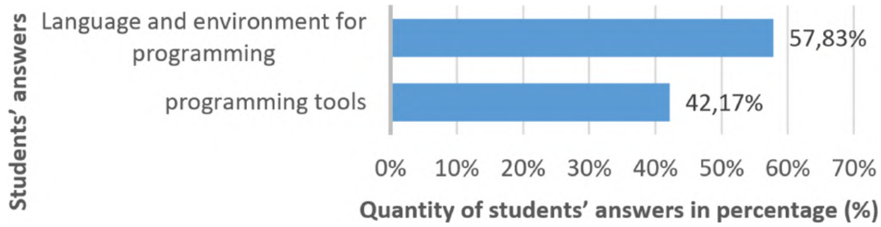

Figure 6: Respondents' answers regarding choosing the mean of solving the tasks of statistical data analysis.

So, students in the class will be asked to use the programming language R as the main tool for practical calculations. MS Excel and Statistica will be used as aids in statistical analysis.

3. Using applied tasks for teaching statistics

Taking into account and summarizing the results of the study, in our opinion, it is advisable to build the content and structure of the course considering the wishes of students. In practical classes, tasks that are of a real applied nature and based on real statistics should be considered. One of the main teaching methods should be a practical method of learning based on programming. The means of statistical data analysis in practical classes can be both software tools for data analysis (MS Excel and Statistica) and the language and programming environment R.

A system of tasks has been developed for the course. Let's consider an example for training of the statistical analysis in the R environment. For carrying out the analysis we will take data from the website https://abit-poisk.org.ua, namely data concerning entrants for 2017. This site contains large amounts of data, for our example we will take only entrants who entered the Faculty of Physical and Mathematical Computer and Technological Education of Berdyansk State Pedagogical University in the specialty "Professional Education (Computer Technology)" and "Professional Education (Digital Technology)", the level of "bachelor".

A total of 31 applications were submitted for these specialties. We will analyze these data, using descriptive statistics in R and present the results using the most common graphs in R when analyzing this data.

Step 1. We set the name, specialty, id, total score of the external evaluation, status (budget / contract), then enter the data into the table. We will set the value in the form of vectors with the command `<- c (’’vector_value1’’, ‘‘vector_value2’’,. . . )`. We build the table from the received vectors by means of the command > `studentdata`. Commands for a table creation with the information about applicants:

```
> last_name <-c(’’Shvachko’’, ‘‘Dybiaga’’, ‘‘Kartashov’’, ‘‘Sytosenko’’,
‘‘Filipenko’’, ‘‘Klimenko’’, ‘‘Veretelnik’’, ‘‘Diakov’’,’’Salionov’’,
‘‘Bagnuk’’, ‘‘Kombarov’’, ‘‘Baranovsky’’, ‘‘Kiseliov’’, ‘‘Sakun’’, ‘‘Bova’’,
‘‘Potapova’’, ‘‘Kobzar’’, ‘‘Sementsov’’, ‘‘Cybulka’’, ‘‘Teplov’’,
‘‘Mitushkin’’, ‘‘Kartinik’’, ‘‘Gavrylenko’’, ‘‘Trotsenko’’,
‘‘Panchukov’’, ‘‘Kyslynsky’’, ‘‘Sagirov’’, ‘‘Korobov’’,
```

```
‘‘Shatalina’’,’’Tichovod’’,’’Popov’’)
> specialty <-c(1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,
1,1,1,1,1,2,2,2,2,2)
> id <-c(1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,
21,22,23,24,25,26,27,28,29,30,31)
> rating <-c(186,184,180,179,173,173,170,168,167,166,163,
162,160,156,148,145,145,142,142,140,140,139,135,131,129,123,
147,146,140,136,128)
> status <-c(1,1,1,1,1,1,1,1,1,1,1,1,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,1,1,1,1,0)
> studentdata <- data.frame(id, last_name, rating, status)
> studentdata
   id  last_name rating status
1   1   Shvachko    186      1
2   2    Dybiaga    184      1
3   3  Kartashov    180      1
4   4  Sytosenko    179      1
5   5  Filipenko    173      1
6   6   Klimenko    173      1
7   7 Veretelnik    170      1
8   8     Diakov    168      1
9   9   Salionov    167      1
10 10     Bagnuk    166      1
11 11   Kombarov    163      1
12 12 Baranovsky    162      1
13 13   Kiseliov    160      0
14 14      Sakun    156      0
15 15       Bova    148      0
16 16   Potapova    145      0
17 17     Kobzar    145      0
18 18  Sementsov    142      0
19 19    Cybulka    142      0
20 20     Teplov    140      0
21 21  Mitushkin    140      0
22 22   Kartinik    139      0
23 23 Gavrylenko    135      0
24 24  Trotsenko    131      0
25 25  Panchukov    129      0
26 26  Kyslynsky    123      0
27 27    Sagirov    147      1
28 28    Korobov    146      1
29 29  Shatalina    140      1
30 30   Tichovod    136      1
31 31      Popov    128      0
```

Step 2. We will calculate the main statistical values: average, median, standard deviation, minimum and maximum value. The results of the main statistical values calculation:

```
> y <- mean(rating)
> y
[1] 153
> sd <-sd(rating)
```

```
> sd
[1] 18.03145
> var <-var(rating)
> var
[1] 325.1333
> mad <-mad(rating)
> mad
[1] 22.239
> min <-min(rating)
> min
[1] 123
> max <-max(rating)
> max
[1] 186
```

According to the results of the calculations, the following data were obtained: the average score of entrants with external evaluation is 153, the average difference between the scores of different entrants is 22 points, the lowest result (min) – 123 points, the best result (max) – 186 points.

Step 3. Let's construct a histogram of frequencies for external evaluation points using the command `> barplot` (figure 7):

```
> counts <- table(studentdata$rating)
> barplot(counts, main=''Frequency diagram'', xlab=''Rating'',
ylab=''Frequency'')
```

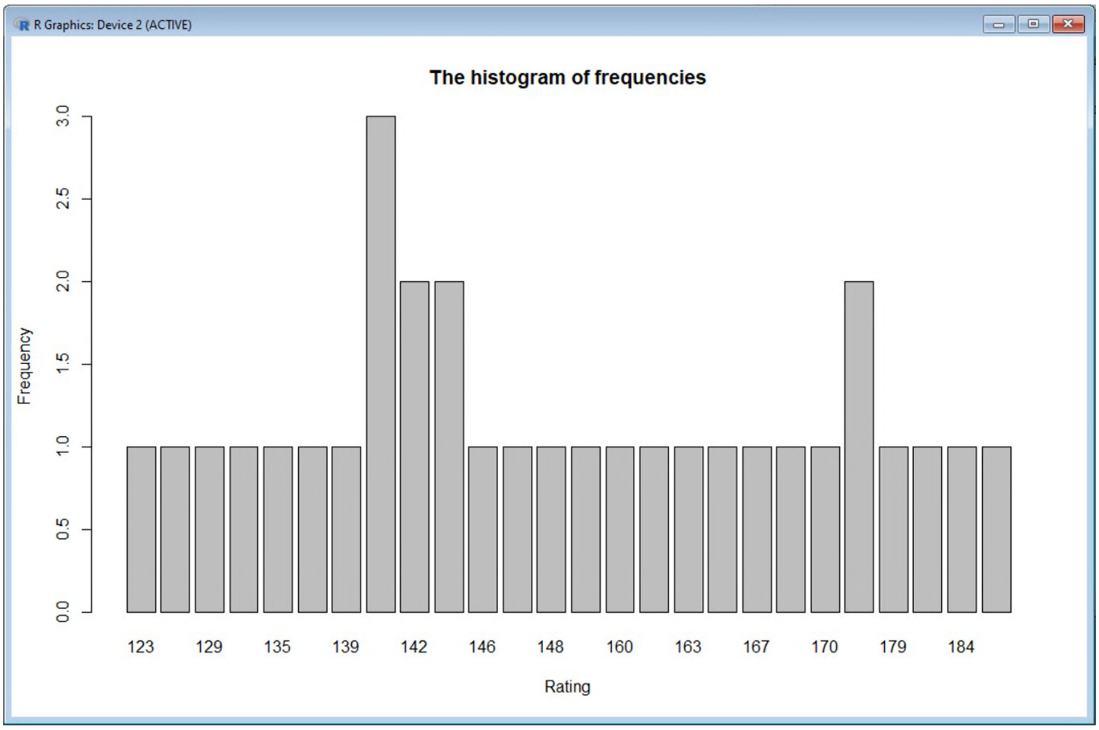

Figure 7: The histogram of frequencies for external evaluation points.

The histogram of frequencies shows that the largest number of entrants has a score from 139 to 142 points, as well as the fact that the vast majority has a unique score with EIT, which is no longer repeated.

Step 4. We construct histograms of points / frequencies with a normal distribution curve. With this purpose we use the command > box. We will build: on the x-axis – the parameter rating, and on the y-axis – the frequency of the score in the table (figure 8):

```
> box()
> library(plotrix)
> x <-studentdata$rating
> h <-hist(x, breaks=12, col=''darkblue'', xlab=''ZNO score'',
main=''Frequencies histogram with the curve of distribution ‘‘)
> xfit <-seq(min(x), max(x), length=40)
> yfit <-dnorm(xfit, mean=mean(x), sd=sd(x))
> yfit <-yfit * diff(h$mids[1:2] * length(x))
> lines(xfit, yfit, col=''red'', lwd=3)
```

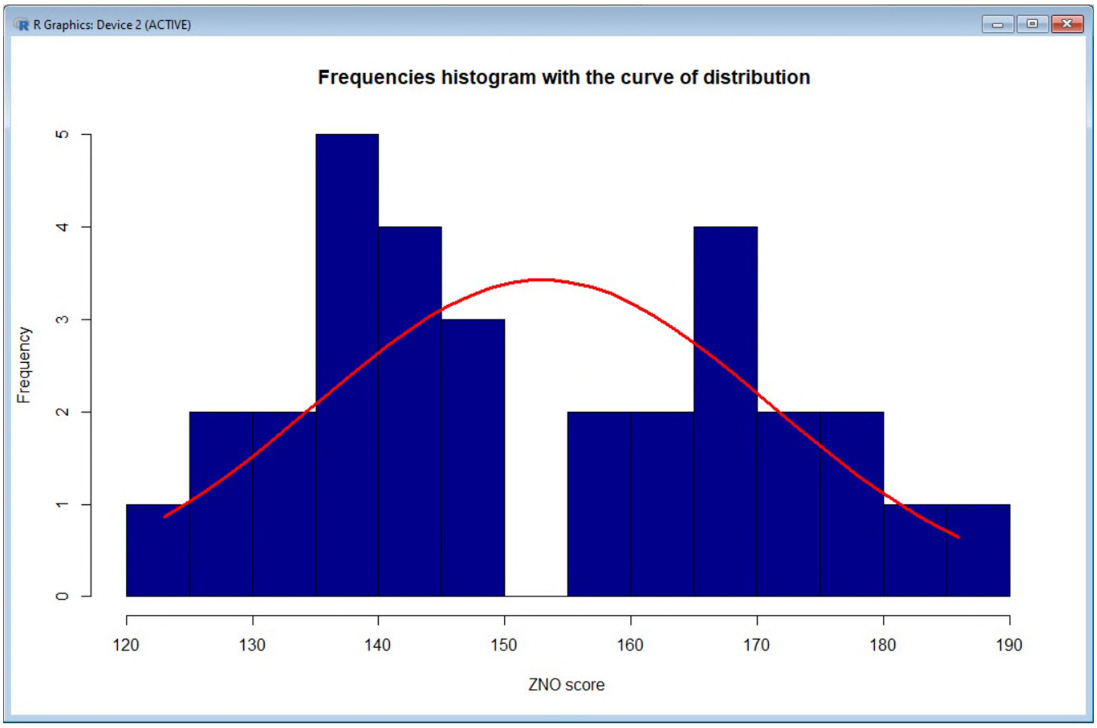

Figure 8: Frequencies histogram with the curve of distribution.

The distribution histogram shows that the data on the scores of applicants are not the subject to the normal law of distribution. We have a lot of “average” entrants, i.e. those who passed the external examination from 135 to 145 points. There are also those who passed 165 points, i.e. entrants with a “sufficient” level. There are very few who scored more than 180 points.

Step 5. We construct a diagram of the nuclear estimation of the density of values for external evaluation points using the command > box (figure 9):

```
> box()
> par(mfrow=c(2,1))
> d <- density(studentdata$rating)
> plot(d)
```

The nuclear density estimation diagram shows that the highest density is observed in the range from 130 to 155 points. That is, in this interval, based on the graph, the values differ by 25 points, then, if you take the full table, they differ by 22 (see standard deviation).

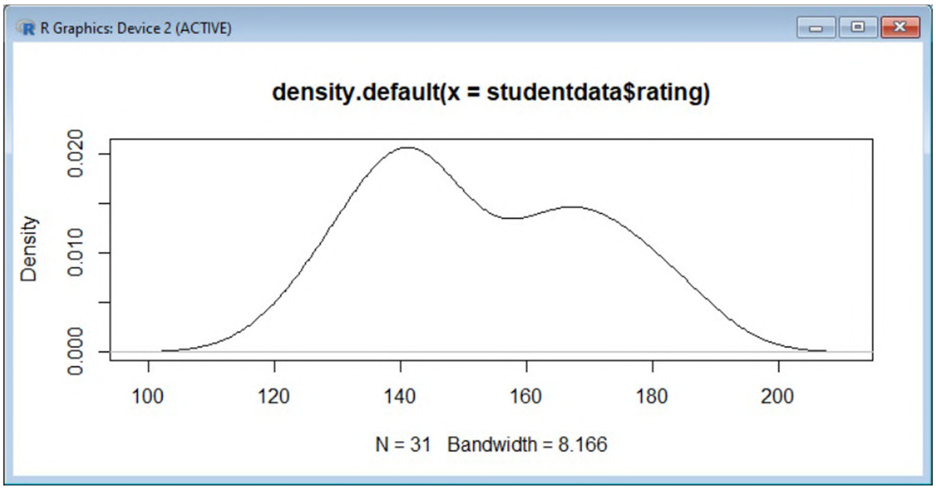

Figure 9: The diagram of nuclear density estimation.

As a result of solving applied problems using theoretical knowledge from different sections of statistics, students will not only master the skills of using statistical methods, but also develop the ability to interpret the results and predict the studied processes. It should be emphasized that the use of programming as a practical teaching method will allow students to improve their knowledge and skills in the field of programming as well as the use of algorithms and design patterns.

Using real data for statistical analysis, students will be able to understand the need and feasibility of statistical research in future professional activities.

One of the problems of using application tasks with real data is the selection and use of data sets. Much of the datasets are closed and inaccessible for free research and use. However, there are organizations that provide free access to data:

- World Bank Open Data (https://data.worldbank.org/) provides more than 3,000 sets of economic and social data on various indicators. Data can be downloaded in csv and xml formats. The service supports API access, which allows you to automate data downloads using the programming language R.
- The unified state web portal of open data (https://data.gov.ua/) contains 15 categories of data sets that are constantly updated. Datasets are available for download in Excel, csv, json and xml formats. All data are available from Creative Commons Attribution 4.0 International license.
- The official page of the All-Ukrainian Population Census (http://database.ukrcensus.gov.ua) provides access to information on the population living in the country, socio-economic characteristics, and demographic indicators, level of education, national composition and language characteristics. Datasets can be downloaded in txt, csv, html formats.
- Open World Health Organization data repository (https://www.who.int/data/gho/). The site provides datasets on the health status of citizens of World Health Organization member states. Datasets are divided into over 100 categories. Data can be downloaded in Excel format or use the API for direct access to data.
- UNICEF Dataset (https://data.unicef.org/) collected relevant data on education, child labor, child disability, infant mortality, maternal mortality, water and sanitation, pneumonia, malaria and more. Datasets are available in Excel and csv formats.
- Registry of Open Data on AWS (RODA) (https://registry.opendata.aws/) contains data located on AWS servers. The service offers access to over 200 datasets. There is a page with additional information, usage examples, license information, and more for each data set. Using the wide range of computing products offered by AWS (Amazon EC2, Amazon Athena, AWS Lambda and Amazon EMR), it is possible to share data in the cloud. This allows users to spend more time analyzing data rather than collecting data. When using data sets hosted on AWS, it is necessary

to consider the type of license of each specific data set, as they belong to different agencies, government organizations, researchers, businesses and individuals.

- Data.gov (https://www.data.gov/) provides open data sets of the US government. The resource contains more than 200,000 data sets from various sources: federal agencies, states, counties, cities, etc. Data can be obtained in various formats, including Excel, csv, json, xml.
- The GroupLens Research (https://grouplens.org/) provides several sets of movie ratings data provided by MovieLens users. The kits contain movie ratings, movie metadata (genre and release year), and user demographics (age, gender, and occupation). Such data can be used to develop a recommendation system based on regression analysis.
- Open data sets Yelp (https://www.yelp.com/dataset) is a subset of our businesses, reviews, and user data for application in personal, educational, and academic purposes. Available as JSON files, use it to teach students about databases, to learn NLP, or for sample production data while you learn statistics.
- Kaggle (https://www.kaggle.com/datasets) a social network for researchers, which provides access to various data sets for analysis and research. The convenience of Kaggle is that it is not just a data warehouse. Each data set brings together a community of researchers in which data are discussed and approaches to data processing are elucidated.
- Google Public Data Explorer (https://www.google.com/publicdata/directory) provides access to more than 130 datasets submitted by World Bank, U. S. Bureau of Labor Statistics, OECD, IMF and other organizations.

All considered services provide access to open data sets. This allows you to fill the content of teaching statistics for future programmers with the tasks of applied direction.

4. Experimental verification of the effectiveness in the use of applied tasks to teach statistics to the future programmers

Using programming language R and tasks of applied direction while training statistics with future IT specialists.

The main purpose of the pedagogical experiment is to test the hypothesis that the use of programming language R and applied problems in teaching statistics to the future IT professionals will help increase the educational motivation of students.

According to the hypothesis of the study, the experiment involved checking the level of motivation of students of IT specialties in the field of statistics based on the results of implementation of applied problems and programming language R. The experiment was conducted on the basis of Berdyansk State Pedagogical University. Students majoring in 015 Professional Education (Digital Technology) and 015 Professional Education (Computer Technology) took part in it.

Control and experimental groups were organized. In the control group, the educational process was carried out according to the traditional methods. This technique involved the use of specialized software (Microsoft Excel, Statistica, etc.) and synthetic tasks, the content of which did not take into account the specifics of future professional activities of students of IT specialties. The control group (CG) consisted of 42 students. The experimental group used application problems and the programming language R to solve them. The experimental group (EG) included 32 students.

During the formation of control and experimental groups, their alignment was carried out taking into account the initial level of educational motivation of students.

The success of the pedagogical research was ensured by the application of the standardized methods. This guaranteed the reliability of the results.

Experimental methods of teaching statistics of future programmers using professional tasks and programming language R was based on their application at all stages of learning: in learning new material as a motivating task, at the stage of consolidation, in independent work of students as a professionally oriented project.

An electronic learning tool has been developed for students programmers to provide information and methodological support for the statistics course. The development of an electronic tool takes into account students age and preparation level. The developed learning tool contains theoretical materials, tasks for practical implementation, visual materials with examples of the application of the programming language R, a guide to the commands of the R language and a list of recommended reading. The e-learning tool is available on the Internet at the link https://r.ktuni.bdpu.org/.

In order to test the effectiveness of the implemented experimental training, the level of educational motivation was chosen as a criterion. To assess the dynamics of changes in motivation to study statistics, future IT specialists used the method of Rean and Yakunin [29] aimed at diagnosing educational motivation in general in order to identify the predominant types of motives for learning. The technique allows identifying the predominant type of motives and to trace the dynamics of changes in the structure of educational motivation. The methodology is standardized and involves the study of 16 types of educational motives of students.

Positive motivation for learning ensures the successful formation of knowledge and skills. High positive motivation can compensate for insufficiently high abilities of students. With the right choice of means of motivation for learning, there is a positive pedagogical influence. Focusing only on "negative" motives (avoidance, fear of failure, fear) is always less effective than "positive" ones. In our study, we will determine the impact of the developed system of tasks on the level of educational motivation of students.

Table 1 presents the results of calculating the average scores for each type of educational motives on the scale of Rean and Yakunin [29]. Comparative analysis of table 1 allows us to conclude that before the experiment the levels of educational motives of students in the control and experimental groups did not differ. After the experiment in the experimental group there is an increase in the levels of the internal educational motives of students. In general, the level of educational motivation in the experimental group is higher than in the control group, except for the motives of avoiding failure and punishment.

Table 1
The results of students' questionnaire according to the methods of Rean and Yakunin [29].

Educational motivation	Before the experiment		After the experiment	
	CG	EG	CG	EG
1. To become a qualified specialist	6.6	6.6	6.7	6.8
2. To get the diploma	6.7	6.6	6.2	6.8
3. To continue successful studies at further courses	5.6	6.3	6.0	6.2
4. To study successfully, to pass exams for "good" and "excellent" marks	6.0	5.3	4.5	6.2
5. To get constant scholarship	5.5	5.2	4.9	5.5
6. To gain deep and profound knowledge	6.0	6.3	6.3	6.8
7. To be always ready for classes	4.5	4.5	5.0	5.2
8. Not to give up learning the subjects of the educational cycle	5.5	5.6	5.5	6.5
9. Not to lag behind the classmates	6.0	5.6	5.5	5.8
10. To provide future successful professional activity	6.8	6.6	6.5	6.9
11. To execute pedagogical requirements	5.0	4.7	5.2	5.5
12. To get teachers' respect	4.8	5.2	3.6	4.9
13. To be an example for the classmates	3.2	4.7	3.5	4.3
14. To gain parents' and relatives' respect	4.5	4.8	5.0	6.6
15. To avoid condemnation and punishment for bad studying	4.1	4.9	5.0	4.5
16. To get intellectual satisfaction	4.9	4.91	4.5	6.6

Table 2 shows the results of statistical comparison of the control and experimental groups before

Table 2
Statistical comparison of the students of control and experimental groups educational motivation levels before and after the experiment.

Before the experiment			After the experiment		
W_{emp}	W_{crit}	Taken hypothesis	W_{emp}	W_{crit}	Taken hypothesis
0.1508	1.96	H_0	2.186	1.96	H_1

and after the experiment. The following statements were formulated as working hypotheses: H_0 – levels of learning motivation in the compared groups do not differ; H_1 – levels of motivation to learn in the compared groups differ. The Mann-Whitney U-test was used to determine the difference between the samples. This is a non-parametric statistical criterion used to estimate the difference between two samples at the level of any qualitatively measured trait. It allows you to detect differences in the value of the parameter between small samples.

Statistical analysis allows us to conclude that at the level of significance $\alpha = 0.05$ the initial states of the experimental and control groups (before the experiment) coincide. At the end of the experiment, the levels of educational motivation differ.

So, the results of the study indicate that the hypothesis of the study was confirmed, namely the introduction of statistics of the R programming language and applied problems in the learning process helps to increase the level of educational motivation of future IT professionals.

5. Conclusions

This paper has provided a theoretical justification for the introduction of innovative approaches to teaching statistics. It has shown that the teaching of statistics to future programmers should be based on the use of applied tasks developed with real data sets obtained from statistical research. Such tasks can increase the students' motivation and interest compared to synthetic examples, which are often used in statistics courses.

Real data sets for statistical analysis are a rich source of applied tasks. They are freely available on the Internet and cover various subject areas, such as sociology, medicine, engineering, economics and biology. Therefore, the development of practical and laboratory work for future IT professionals should include tasks that involve real data from these domains.

Using the R programming language to teach statistics to future programmers allows the use of a practical training method based on programming. This method engages students in familiar and relevant activities and develops their programming skills. Therefore, we propose to use R as the main tool for teaching statistics. MS Excel and Statistica software packages can be used as supplementary tools.

In further research, we plan to develop a methodology for implementing and applying R and Python programming languages for statistical data analysis.

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Methodology for teaching development of web-based augmented reality with integrated machine learning models

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Abstract

Augmented reality (AR) is an emerging technology with many applications in education. Web-based augmented reality (WebAR) provides a cross-platform approach to deliver immersive learning experiences on mobile devices. Integrating machine learning models into WebAR applications can enable advanced interactive effects by responding to user actions. However, little research exists on effective methodologies to teach students WebAR development with integrated machine learning. This paper proposes a methodology with three main steps: (1) Integrating standard TensorFlow.js models like handpose into WebAR scenes for gestures and interactions; (2) Developing custom image classification models with Teachable Machine and exporting to TensorFlow.js; (3) Modifying WebAR applications to load and use exported custom models, displaying model outputs as augmented reality content. The methodology is designed to incrementally introduce machine learning integration, build an understanding of model training and usage, and spark ideas for using machine learning to augment educational content. The methodology provides a starting point for further research into pedagogical frameworks, assessments, and empirical studies on teaching WebAR development with embedded intelligence.

Keywords

web-based augmented reality, WebAR, machine learning, TensorFlow.js, Teachable Machine, educational technology

1. Introduction

Web-based Augmented Reality (WebAR) is one of the most common ways to combine the real and the virtual on mobile Internet devices [1, 2]. The development of web-based augmented reality applications differs from other development methods in that it is cross-platform and does not require the installation of developed applications, which significantly increases the level of software mobility compared to traditional mobile applications [3, 4].

Currently, the world's most famous non-profit library for WebAR development is AR.js [5], founded by Jerome Etienne (for example, [6] provides a systematic description of the possibilities of using AR.js for the development of professional competences of future teachers of STEM disciplines), but HiuKim

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Yuen [7], one of the developers of AR.js, created a new library called MindAR [8], which is more compact and technologically advanced, but, unlike AR.js, is little known.

AR.js and MindAR are built on the classic ARToolKit and OpenCV engines, respectively, which are currently the industry standard. At the same time, while AR.js is focused on processing primarily simple markers up to 16×16, MindAR is focused on natural images of complex structures. Another feature of MindAR that makes it an appropriate learning tool is the inclusion of the well-known TensorFlow machine learning library [9], which provides potential opportunities for integrating machine learning models into WebAR applications to create highly interactive and exciting effects, such as using hand gestures or facial expressions to control AR content.

The aim of the study is to develop the methodology for teaching the development of augmented reality for the Web with integrated machine learning models.

The main **objectives of the study** are as follows:

1. Perform a bibliometric analysis of sources from educational applications of WebAR.
2. Choose tools for developing augmented reality for the Web.
3. Develop and test a methodology for developing WebAR applications for face tracking.
4. Develop and test a methodology for integrating machine learning models into WebAR applications.

2. Bibliometric analysis of sources from educational applications of WebAR

To perform a systematic bibliometric analysis for the queries "WebAR" and "Web-based augmented reality for education", VOSviewer version 1.6.18 [10] was used.

As a data source for the first query, Crossref was selected with a search by document titles, which made it possible to select 19 documents from 2017-2022 (date of request: 26.11.2022). The selected documents were analysed by the times they were co-cited with other documents.

Out of 92 sources cited in 19 documents, 26 are cited together more than once, forming only 1 cluster (figure 1), which includes works [1, 2, 11], performed under the supervision of Serhiy O. Semerikov.

Scopus was chosen as the data source for the second query, with a search by titles, abstracts and keywords, which made it possible to select 93 documents from 2001-2023 (figure 2), 66 of which are from the last five years. The majority of them are journal articles (58 [12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69]), the smaller part is books (4 [70, 71, 72, 73]) and articles in conference proceedings (31 [74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104]).

Out of 301 authors of 93 documents, 27 were cited twice or more times and 9 were cited three or more times. figure 3 shows the semantic network of keywords in the documents for the query "Web-based augmented reality for education". The distribution of keywords by clusters (figure 4) is shown in table 1.

The first cluster (highlighted in red in figure 4 and table 1) connects the **basic concepts of augmented reality in education**: augmented and virtual reality with education (including medical education) and human learning, including the use of smartphones.

Augmented reality is a systemic element – it connects all the clusters and is itself connected to all other concepts.

In the analysed documents, *virtual reality* is not linked to traditional, mobile, and Internet/web-based learning. It is essential to distinguish virtual reality from virtual learning environments, which include these concepts.

The concept of *education* is also almost universal – it is not only associated with user interfaces and AR applications.

The links of *medical education* with other clusters are quite revealing: in the second cluster – with the concepts of curricula, computer-aided instruction, education computing, e-learning and students; in the third – with websites and pedagogical augmented reality technology, in the fourth – with distance education.

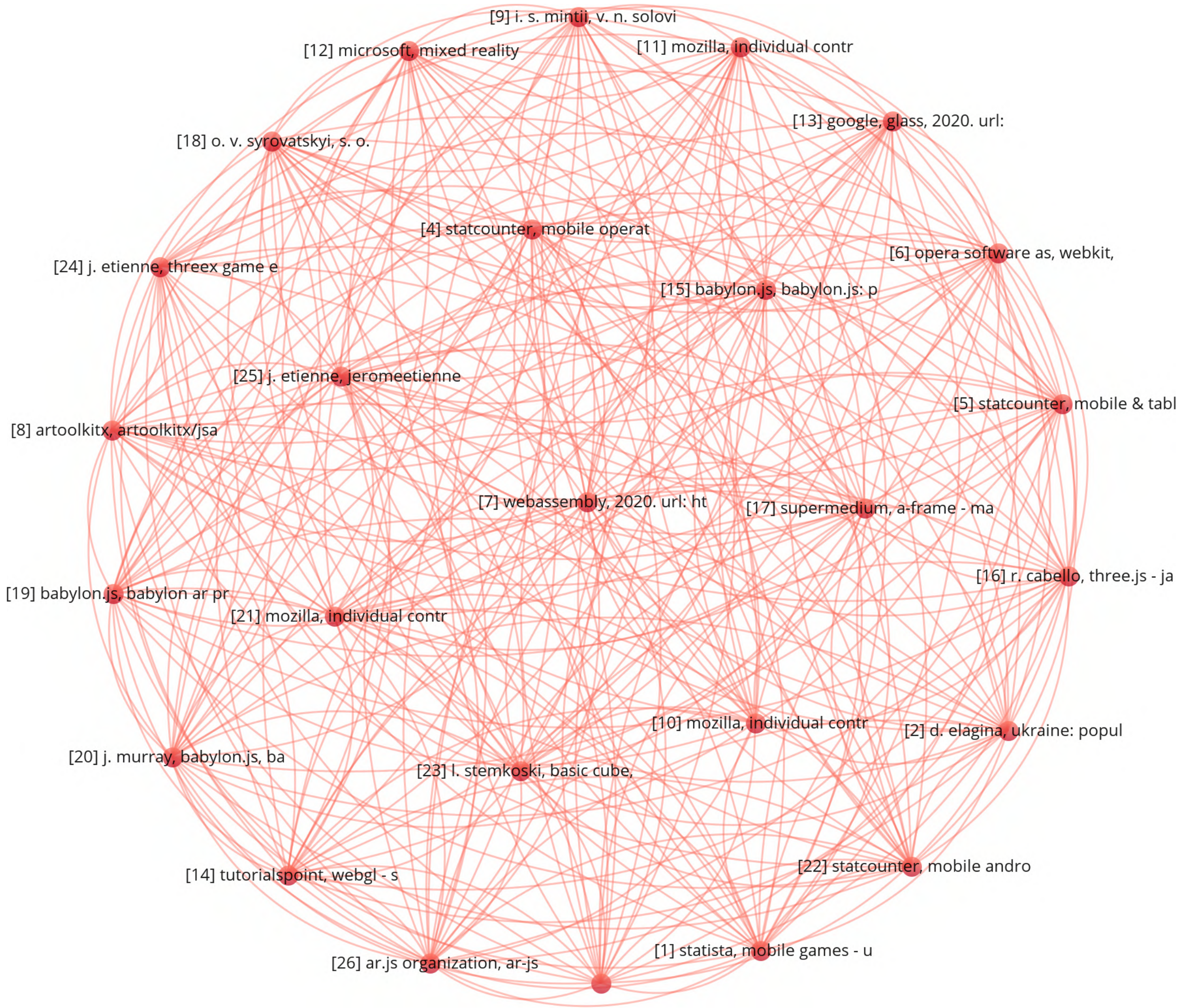

Figure 1: The semantic network of links in the documents for the query “WebAR”.

Learning (in the sense of studying) is related in the second cluster to teaching, students, education computing, computer-aided instruction, e-learning and user interfaces, and in the third cluster to websites and motivation. This concept has no direct links to distance education.

The concept of a *human(s)* (person(s)) outside their cluster is linked to students and e-learning in the second cluster and websites in the third.

Outside of its cluster, *Internet/web-based learning* is only associated with traditional teaching in the second cluster.

Finally, *smartphones* are linked in the second cluster to teaching, students, education computing, e-learning and engineering education, and in the third cluster to websites and augmented reality applications.

The second cluster (highlighted in green in figure 4 and table 1) connects the **concepts of learning environment design**: teaching, engineering education, computer-aided instruction, e-learning, students, mobile learning, learning environments, education computing, and curricula.

Central to the second cluster are the concepts of *“e-learning”* and *“students”*, which are also almost universal – formally, they are not associated only with Internet/web-based learning due to their synonymity with e-learning.

Computer-aided instruction is related to the concepts of the first (augmented and virtual reality, education (including medical) and learning) and third (motivation, websites, learning systems, interactive learning environments, augmented reality applications, augmented reality technology) clusters.

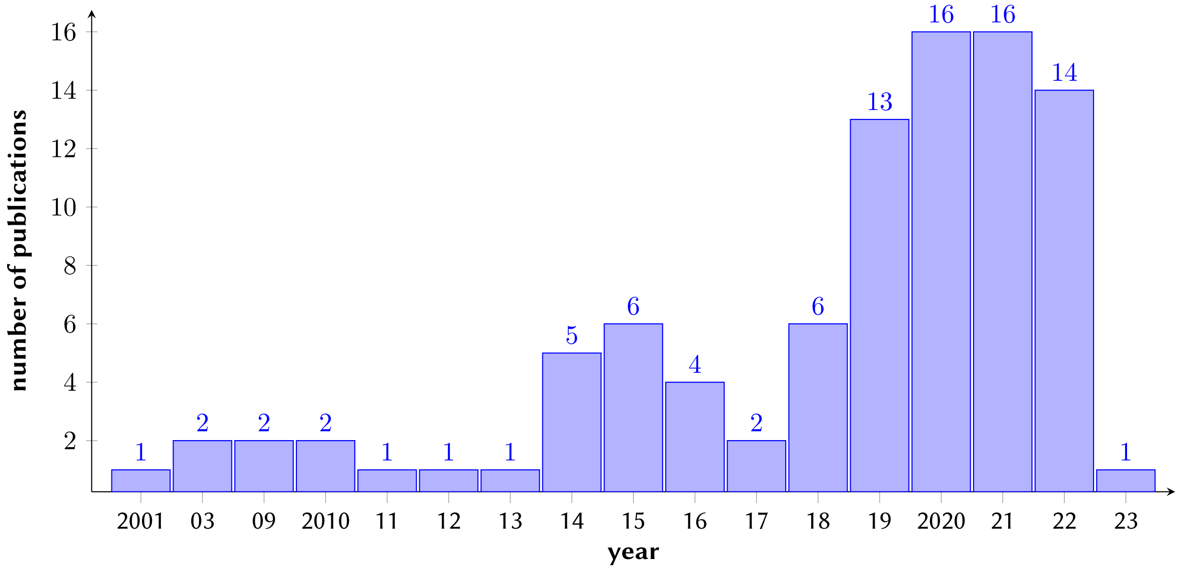

Figure 2: Distribution of documents by year (query “Web-based augmented reality for education”).

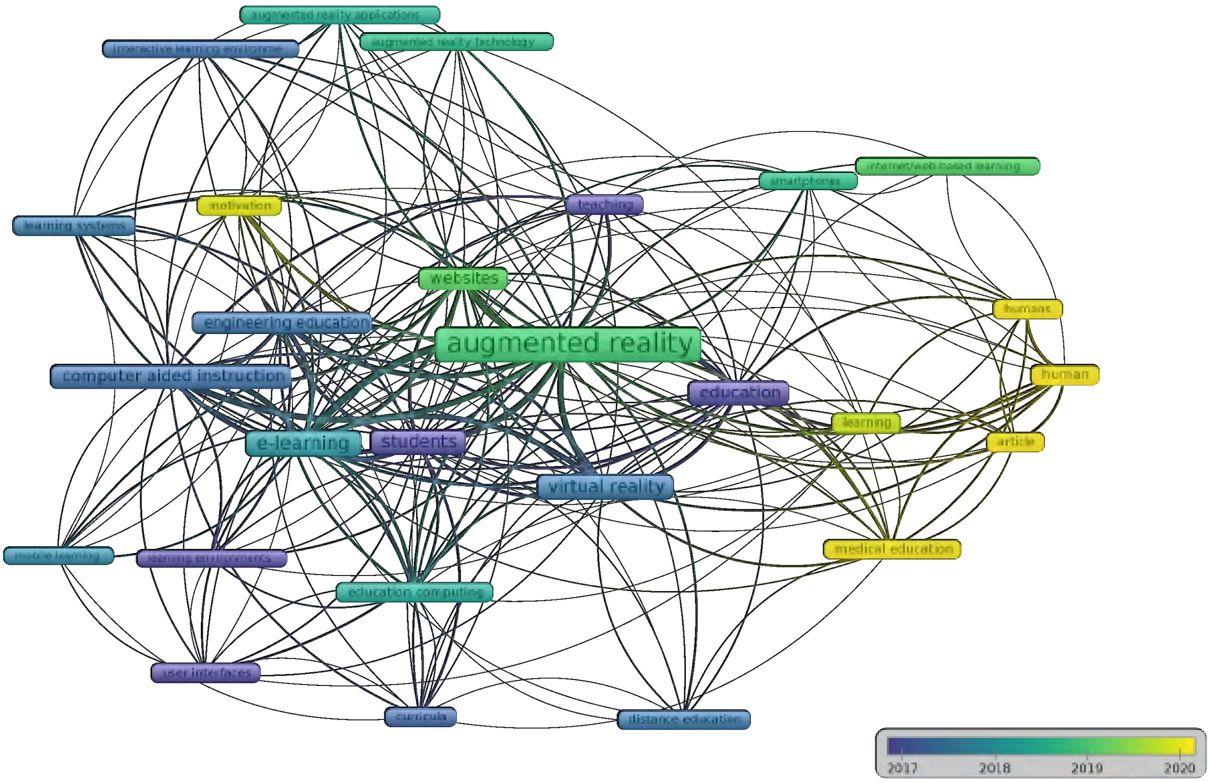

Figure 3: The semantic network of keywords in documents by the query “Web-based augmented reality for education”.

The concept of *teaching* is linked in the first cluster to augmented reality, education and learning, smartphones and Internet/web-based learning, and in the third cluster to websites, augmented reality applications and augmented reality technology.

Engineering education is related in the first cluster to augmented and virtual reality, education and smartphones, and all concepts of the third and fourth clusters.

Education computing is related in the first cluster to augmented and virtual reality, education (including medical) and learning, smartphones, and in the third cluster to motivation, learning systems and websites,

Table 1
Distribution of keywords by clusters (documents by query "Web-based augmented reality for education").

Cluster 1	Cluster 2
article	computer-aided instruction
augmented reality	curricula
education	e-learning
human	education computing
humans	engineering education
internet/web-based learning	learning environments
learning	mobile learning
medical education	students
smartphones	teaching
virtual reality	user interfaces

Cluster 3	Cluster 4
augmented reality applications	distance education
augmented reality technology	
interactive learning environments	
learning systems	
motivation	
websites	

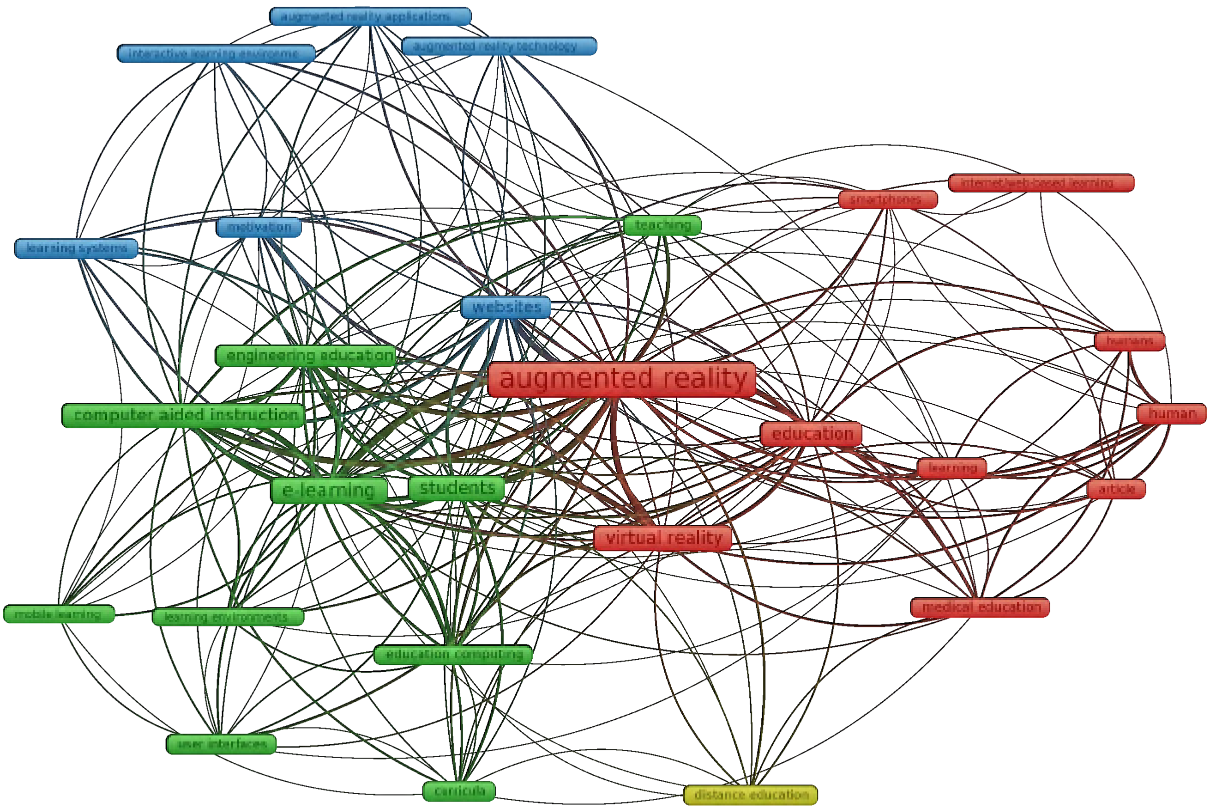

Figure 4: Distribution of keywords by cluster.

and the fourth – with distance education.

Outside their cluster, *learning environments* are only related to augmented and virtual reality education from the first cluster and websites from the third.

Similarly, *mobile learning* is related to education and augmented reality in the first cluster and motivation, websites and learning systems in the third.

User interfaces have links to the concepts of the first (learning, augmented and virtual reality) and third (motivation, websites) clusters.

The *Curricula* are related to education (including medical education), augmented and virtual reality in the first cluster, websites in the third cluster, and distance education in the fourth cluster.

The third cluster (highlighted in blue in figure 4 and table 1) connects the **concepts of immersive learning environment implementation**: websites, motivation, learning systems, interactive learning environments, augmented reality applications and augmented reality technology.

Central to the third cluster are *websites*, which are almost universal concepts – formally, they are not associated only with Internet/web-based learning due to the overlap of the relevant concepts.

The concept of *motivation* is related in the first cluster to augmented and virtual reality, education and learning, and in the third cluster to e-learning and mobile learning, education computing, user interfaces, computer-aided instruction, students and engineering education.

Learning systems are related in the first cluster to augmented and virtual reality and education and in the third cluster to e-learning and mobile learning, education computing, computer-aided instruction, student-centred teaching and engineering education.

Interactive learning environments also have similar links: in the first cluster, with augmented and virtual reality and education, and in the third cluster, with e-learning, computer-aided instruction, students and engineering education.

Naturally, *augmented reality applications* are related to augmented reality and smartphones in the first cluster and to e-learning, computer-aided instruction, teaching, students and engineering education in the second.

Augmented reality technology are related in the first cluster to augmented and virtual reality and education (including medical education) and in the second cluster to e-learning, computer-aided instruction, teaching, students and engineering education.

The fourth cluster (highlighted in yellow in figure 4 and table 1) contains the **concept of distance education**, which is linked in the first cluster to the concepts of augmented and virtual reality and the concept of education (including medical education), in the second cluster to the concepts of student, engineering education, education computing, e-learning and curricula, and in the third cluster to the concept of website.

The analysis of the distribution of concepts by the density of links (figure 5) and time makes it possible to determine that the oldest (before 2015) studies focused on user interfaces and their application in education. In 2016, the focus shifted to studying the impact of teaching in learning environments on students. In 2017, the research actualised the concepts of virtual reality, interactive learning environments, curricula, and computer-aided instruction in engineering education. The focus of research in 2018 was on education computing, the use of smartphones, augmented reality applications and pedagogical augmented reality technology.

WebAR is the focus of research in 2019, with studies addressing the use of smartphones, online/web-based learning and augmented reality. In 2020, the impact of the COVID-19 pandemic added to the issues of learning motivation and medical education. A new element of recent research is human augmentation.

3. Augmented reality development tools for the Web

3.1. Setting up a web server and remote debugger

The main development tools to develop in HTML and JavaScript are a simple text editor and a web browser, where you can open a regular HTML web page saved locally.

However, this may not work for applications that require a camera. In addition, you may want to test applications on your own mobile devices from time to time, so it is best to install a local web server like Simple Web Server.

It may be helpful to select the HTTPS protocol in the advanced settings – without it, the mobile device may not be able to access the camera.

Figure 5: The density of keyword connections for the query "Web-based augmented reality for education".

Doing all the development and testing work directly on a desktop browser is possible, but sometimes, it is still worth trying on a mobile phone.

If the devices are connected to the same local area network that does not have a firewall, there is no problem accessing the web server. However, if the network access point is behind a firewall, you can use ngrok to redirect traffic from the restricted port.

After installing ngrok and creating an account on the website [105], you need to register the ngrok agent [106] and start it, specifying the protocol (e.g. HTTP) and the port number that the firewall denies access to (e.g. 8887).

Once started, ngrok provides a global HTTPS Internet link – but only while the local web server and the ngrok redirect are running.

Traditionally, debugging web applications involves viewing the web browser console, which displays notifications related to debugging the application.

However, it may be challenging on a mobile device. Here, RemoteJS [107] will help – by clicking the `Start Debugging` button after going to the site, we will get the RemoteJS agent code like this:

```
<script data-consolejs-channel="9817ec3e-a3f7-fbe3-3836-e2e2d07d5c99"
  src="https://remotejs.com/agent/agent.js">
</script>
```

This code should be copied and pasted directly into the web page.

After that, all debug messages will be sent to the web page at https://remotejs.com/viewer/agent_code, where `agent_code` is the value of the `data-consolejs-channel` variable.

3.2. Application of a graphical library for augmented reality on the Web

WebGL [108] is a JavaScript API for rendering 3D graphics in browsers. It is a cross-platform display standard supported by all major browsers. However, low-level WebGL code is difficult to read and write, so more user-friendly libraries have been created.

Three.js [109] is one such library. Its author, Ricardo Miguel Cabello, also known as mrdoob, is one of the pioneers of WebGL, so this library is often used when building other libraries. Most WebAR SDKs support Three.js, so it is a must-have language for effectively developing augmented reality web applications.

To understand how Three.js works at a high level, it is useful to draw an analogy with the work of a photographer or film director who:

1) customises the scene by placing objects on it;
2) moves the camera to capture footage from different positions and angles.

Three.js is not a specialised library for augmented reality – it contains much more functionality, including that which is more suitable for web VR (lighting, cameras, etc.) (figure 6).

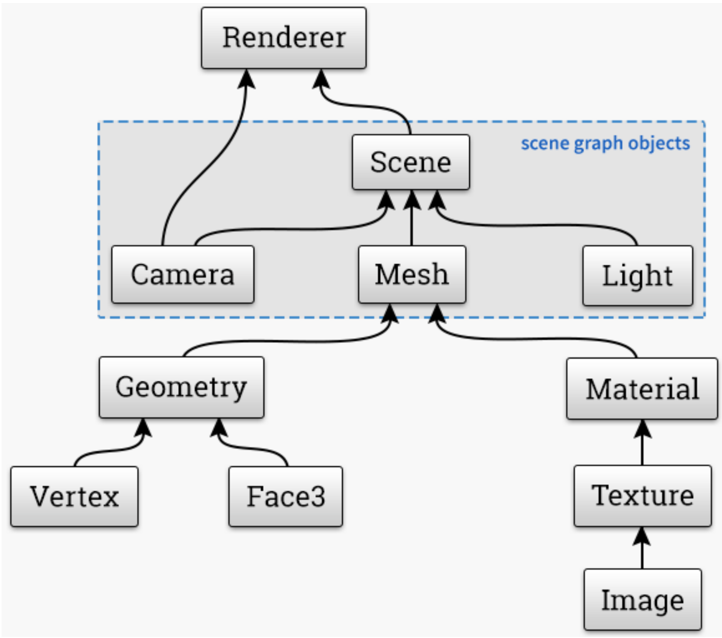

Figure 6: The general structure of Three.js.

As shown in figure 6, the basis is a scene where objects are created in three steps:

1) determination of object geometry – position vectors, colours, etc.: e.g., `BoxGeometry` is responsible for the rectangular parallelepiped;
2) definition of the material – the way the object is rendered (its optical properties – colour, texture, gloss, etc.): for example, `MeshBasicMaterial` corresponds to a material that has its colour and does not reflect rays;
3) geometry and material composition is performed using `Mesh`.

The renderer will display the 3D model on the canvas, considering the material, texture and lighting. For WebAR applications to work, the scene needs to be transparent so that the video stream from the camera can be overlaid. This is achieved by setting the `alpha` parameter to `true` in the `WebGLRenderer` class constructor.

Rendering itself is performed by the `render` method, which displays the projection of the scene onto the canvas (`canvas` element) from the camera's point of view.

Connect the video stream before linking a canvas to an HTML page for WebAR applications.

figure 7 shows the first implementation of WebAR, in which a real object from the camera is supplemented with a virtual object.

Placing a canvas over the video is the basis of WebAR. The only thing that needs to be added is displaying the object in a more appropriate location and updating its position according to the camera signal, i.e. object tracking.

Figure 7: Video stream and model overlay.

3.3. Setting up a library for augmented reality on the Web

You can change the position of the image by moving the virtual camera, changing its position (coordinates), and tilting it. Appropriate changes require tracking objects, so it is expected to classify augmented reality into marker-based, markerless, location-based, etc.

HiuKim Yuen offers a classification of augmented reality by the type of tracking.

The first type is *image tracking*: in this type, virtual objects appear on top of target images, which can be barcode-like, which have a predefined structure, and natural, which can be anything.

The images do not have to be printed or on-screen – there can even be augmented reality T-shirts [110].

The second type of augmented reality is *face tracking*, where objects are attached to the human face. Examples include Instagram filters, Google Meet, social media campaigns, apps for trying on virtual accessories, etc.

The third type of augmented reality is *world tracking*, also known as markerless augmented reality. With this type of tracking, augmented reality objects can be placed anywhere, not limited to a specific image, face, or physical object.

World tracking applications continuously capture and track the environment and estimate the physical position of the application user. Augmented reality objects are often attached to a specific surface, such as the ground.

Location-based augmented reality, known for Pokémon GO, Ingress etc., involves linking content to a specific geographical location – latitude and longitude. Usually, these apps track the environment, as the augmented content is usually attached to the ground, and the location-based part is rather an additional condition that triggers the tracking of the environment (or a face) in a specific location.

Other types of tracking can be defined, such as 3D object tracking, hand tracking, etc.

Despite the variety of libraries for augmented reality, their main task is to determine the position of the virtual camera following the tracked object, as illustrated by the following pseudocode:

```
const ar_engine = new SOME_AR_ENGINE();
while(true) {
  await nextVideoFrameReady();
  const {position, rotation} = ar_engine.computeCameraPose(video);
  camera.position = position;
  camera.rotation = rotation;
}
```

First, you need to initiate a library – a specific AR engine – and get a link to it. Then, in a continuous loop, wait for a frame from the video stream of the real camera, determine its position (tilt coordinates), and move the virtual camera on the canvas to the same position.

Often, however, it is not the virtual camera that moves but the objects on the scene. In this case, the position of the tracked object is determined, rather than the real camera, and then the virtual reality object is moved to the same position as the tracked object:

```
const ar_engine = new SOME_AR_ENGINE();
while(true) {
  await nextVideoFrameReady();
  const {position, rotation} = ar_engine.computeObjectPose(video);
  some_object.position = position;
  some_object.rotation = rotation;
}
```

The tracked image can be of any origin, but it must be prepared: if it contains unnecessary elements, they should be removed.

To recognise an image using the MindAR library, you need to select landmarks on the image – the elements that will be used for recognition. This can be done using the image compiler available at https://hiukim.github.io/mind-ar-js-doc/tools/compile. Compiling results in the binary file `targets.mind`, which describes the reference points to be tracked.

Other libraries have similar means of obtaining image descriptions, often called NFT (natural feature tracking) marker compilers. Such an image should be visually complex and have a high resolution (details matter here). A visually complex image provides the software many opportunities to track unique and easily recognisable parts of the image.

The physical size of the NFT marker also affects the quality of its recognition: small images should be approached by the mobile device, while large ones should be kept away from it.

The recognition quality also depends on the brightness of the mobile device's screen; low-resolution cameras usually work better when they are close to the markers.

The Three.js library is a part of MindAR, which significantly simplifies their interaction: the `MindARThree` class constructor creates the objects necessary for working with Three.js – renderer, scene, and camera, which are available as `renderer`, `scene` and `camera` fields, respectively.

The anchor objects returned by the call to the `addAnchor` method, whose parameter corresponds to the number of the image to be recognised, are used to track target images and provide the position where the object should be placed.

Instead of adding Three.js objects directly to the scene, they are added to an anchor component – a `group` object of the `THREE.Group`class that defines a set of related objects whose position, orientation, and visibility can be controlled together. This anchor group is managed by the MindAR library, which will continuously update the group's position and orientation in accordance with our tracking set.

The `start` method of the `MindARThree` class sets up the parameters, turns on the camera, and loads all the necessary data into the web browser's memory.

For the renderer, camera, and scene to work, you must create a function to render them. In the unnamed callback function created by the `setAnimationLoop` function, for each frame, the `render` method is called from the `renderer` object, whose parameters are the `scene` and `camera` objects – this is the animation on the canvas.

The result is a fully functional WebAR application that tracks a single image (figure 8).

4. Methodology for developing WebAR applications for face tracking

4.1. Model of facial anchor points

The MindAR library has two main sets of modules – for working with images (`image`) and for working with faces (`face`).

The similarities between the image-tracking and face-tracking APIs are visible in the MindAR code. Despite the similarities, the `addAnchor` method interprets the parameter differently. For image tracking, it was the number of the target image; for face recognition, it is the number of the face reference point.

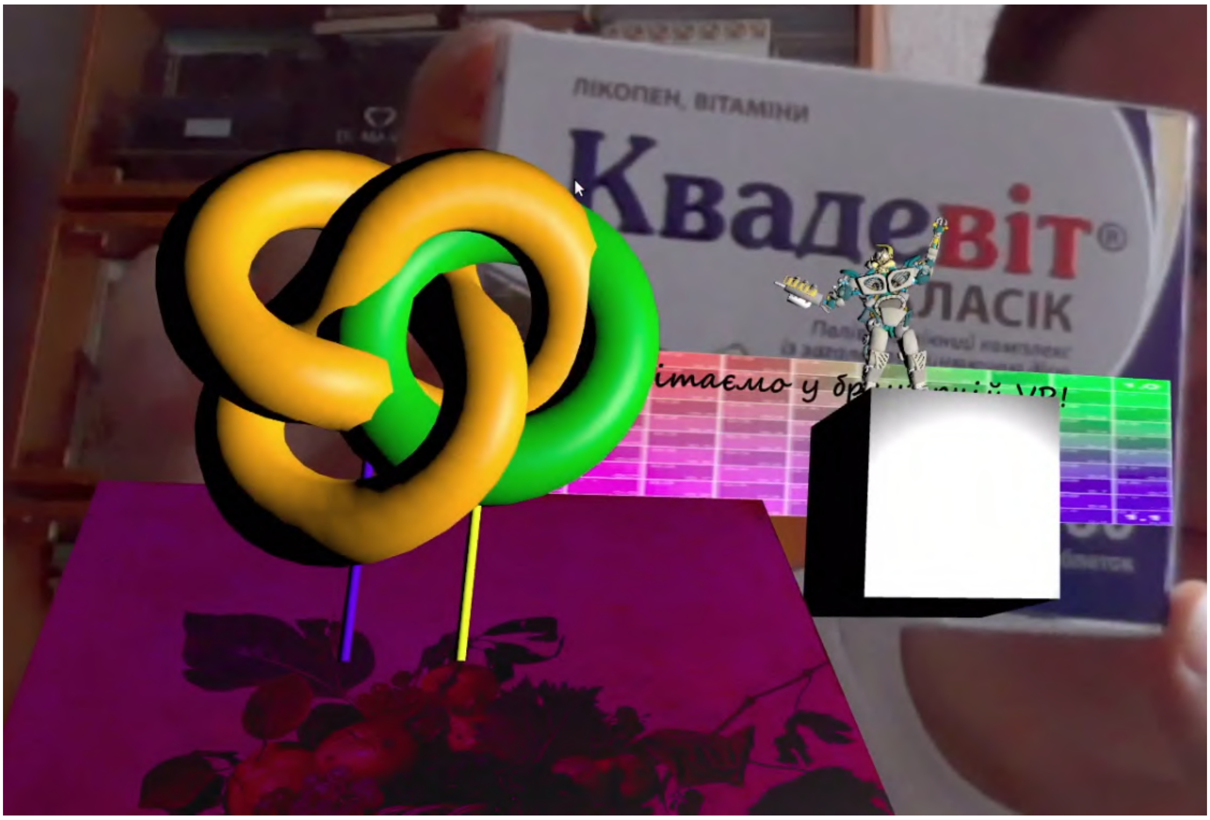

Figure 8: The result of image recognition.

Face landmark detection is based on the well-known TensorFlow library model [111]. MediaPipe Face Mesh model [112] is a convolutional neural network that detects 468 three-dimensional landmarks on the face (https://github.com/tensorflow/tfjs-models/raw/master/face-landmarks-detection/mesh_map.jpg), and we can bind objects to any of them (figure 9).

4.2. Putting a mesh on your face

A face mesh is another type of augmented reality that overlaps images (textures) on all the reference points of a person's face rather than being linked to individual points. Face meshes are used to create various makeup effects, tattoos, etc. – up to full face virtualisation.

The face mesh is not a predefined 3D model – it is dynamically generated with constant geometry updates.

To apply the mesh to the face, we need a suitable texture.

The mesh is created by calling `addFaceMesh`. The `addFaceMesh` method is similar in form to `addAnchor`, but they are different: `addAnchor` creates an empty group to which objects whose position is controlled by MindAR are added, while the `faceMesh` returned by `addFaceMesh` is a single displayed object whose geometry changes in each frame.

The material of the face mesh can be any texture – if you do not set it, the face mesh will look like the one shown in the first image (figure 10).

You can see the structure of this mesh in the second image (figure 10) – to do this, set the `wireframe` attribute of the image material.

The third and fourth images (figure 10) are examples of the modified texture of facial landmarks. In the documentation for Meta Spark Studio [113] you can find a set of textures for face meshes that can be used to create your mesh, as described in [114].

Creating a beautiful mesh requires specific artistic skills, but using the canonical texture (figure 9) is quite simple – apply the desired image over it and remove unnecessary lines.

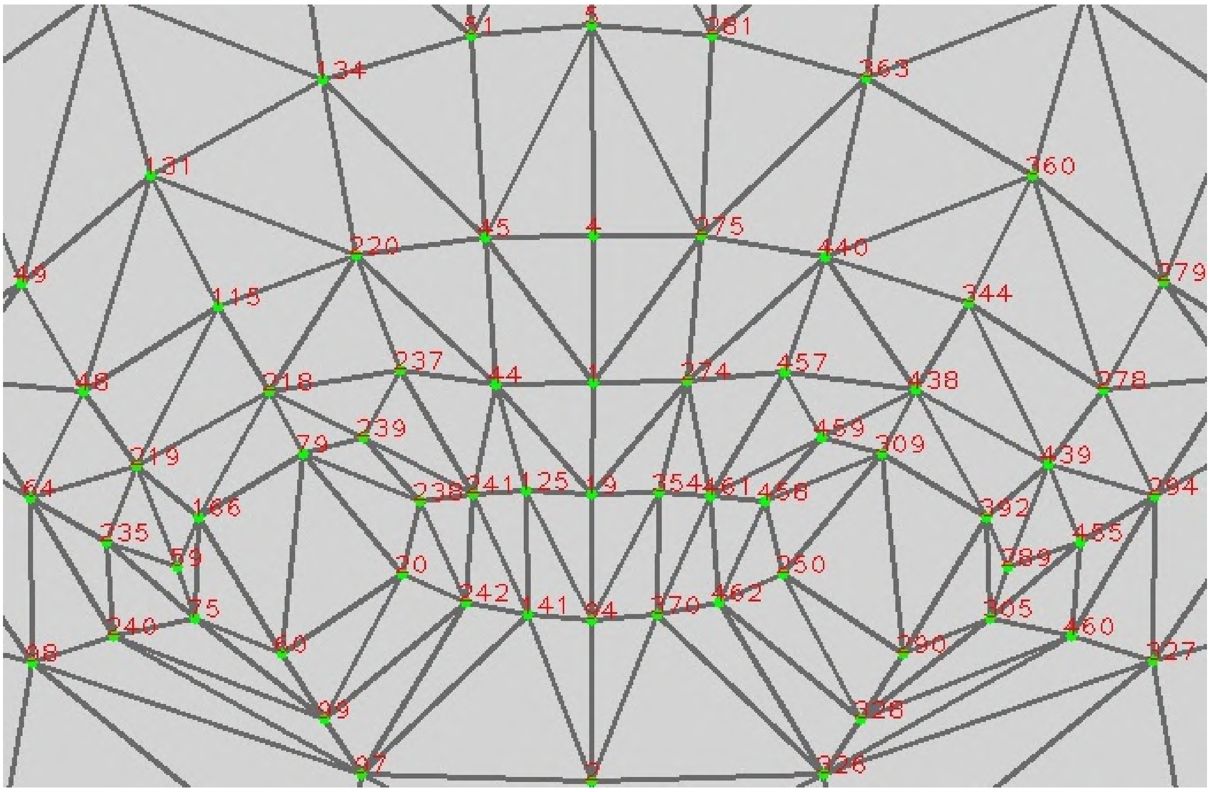

Figure 9: The reference points of the face (fragment).

5. Methodology for integrating machine learning models into WebAR applications

5.1. Integration of standard models

For machine learning on the Internet, TensorFlow [115] is the most commonly used free and open-source machine learning library developed by Google. Currently, it supports many languages, including major ones – Python, Java, and C++ – and community-supported ones: Haskell, C#, Julia, R, Ruby, Rust, and Scala. It is available on many platforms, including Linux, Windows, Android, and embedded platforms – the TensorFlow Lite library version is designed to run machine learning models on mobile devices, microcontrollers, IoT devices, etc.

TensorFlow.js [9] is a JavaScript version of TensorFlow that allows you to develop and use models using this language directly in the browser.

TensorFlow.js has many pre-trained models that can be used immediately [116]. A complete list of currently available models can be found at https://github.com/tensorflow/tfjs-models – many of them are extremely useful and can be an excellent addition to AR applications. If the required functionality is unavailable, you can create and train your models or modify existing ones.

TensorFlow.js is part of the MindAR library. However, models are not part of Tensorflow.js, so they need to be connected separately – as shown in the example of the `handpose.js` model described in [117]. This model is used to define the hand and its components.

The `handpose` model is loaded from the TensorFlow Hub (since 2023, a part of Kaggle) [118]: looking at this model repository, you can see that they take up a considerable amount of space, so the `load` method that loads them is called as an asynchronous function.

The `handpose` model processes individual frames taken from the video stream. This is a rather computationally intensive procedure, so, given that, as long as high accuracy of hand identification is not required, you can try to detect them not in every frame. The `detect` function creates a separate animation loop, in which for every tenth frame, the `estimateHands` method of the loaded model is

Figure 10: Face meshes.

called, and a `video` frame is passed to it. The method returns a `predictions` containing information about the hand images detected in the frame, so a non-zero array size is a sign that there was a hand in the frame:

```
const video = mindarThree.video;

let frameCount = 1;

const detect = async () => {
  if (frameCount % 10 == 0) {
    const predictions = await model.estimateHands(video);
  if (predictions.length > 0) {
    //...
```

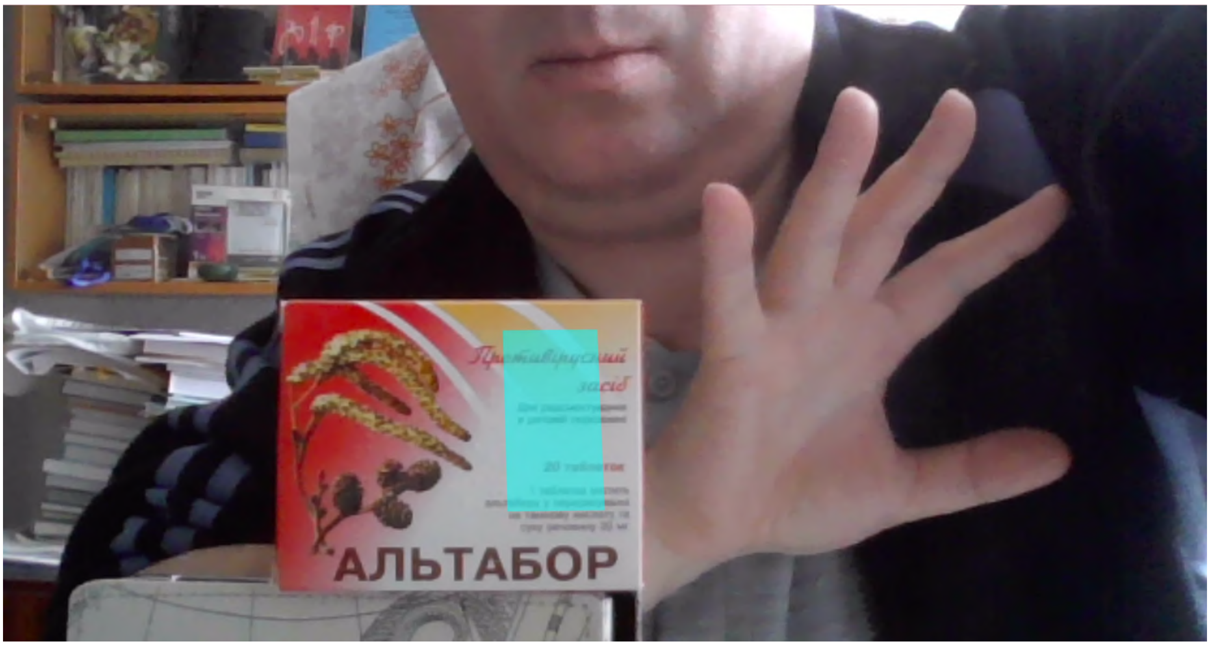

Figure 11: Gesture control of the size and position of a virtual object.

```
  }
  frameCount++;
  window.requestAnimationFrame(detect);
}

window.requestAnimationFrame(detect);
```

figure 11 shows an example of setting the position of the plane in the detected image so that it reflects the position of the bounding box of the hand in the frames – the effect is quite simple, but it provides an idea of how to use machine learning models in AR applications.

5.2. Developing custom models

To quickly create and train your model, you can use the Teachable Machine [119] is a part of the Google AI Experiment project (https://labs.google/ and https://experiments.withgoogle.com/), which allows building models to solve problems of image, sound, and pose classification.

To use the Teachable Machine, students are asked to create a new Google account or use an existing one, and then they can choose the type of model they want to create. There are three types of models available:

- Image recognition model allows you to identify objects in photos;
- Sound recognition model allows you to recognise audio recordings;
- Pose recognition model allows you to recognise body movements.

After selecting the model type, you need to provide data for training it through photos, audio recordings, or videos. Once the data is provided, the Teachable Machine will start training the model, which may take some time, depending on the size and complexity of the training. Once the model is trained, it is advisable to test it to ensure it correctly recognises the data. If the model is inaccurate enough, you can provide additional data to improve it. Once the model has been successfully trained and validated, it can be exported to other projects.

With Teachable Machine's wide range of features, we can recognise sounds, poses, faces, or any image. Nevertheless, to start using it, you must prepare photos and audio recordings for further experiments, train the selected model, and apply it directly to the web environment.

Clicking on the `Get Started` button on the home page will take you to a new window where you can use a project template or create your own.

When creating your project, choose which model you want to use. We choose `Image Project` and click on `Standard image model`. As a source of images, we suggest that students use their webcams and take a series of headshots from different angles (tilt and rotation angles), which we save in a pre-prepared catalogue. We will take several different images from each participant in the experiment and divide them into classes, noting the corresponding names (figure 12).

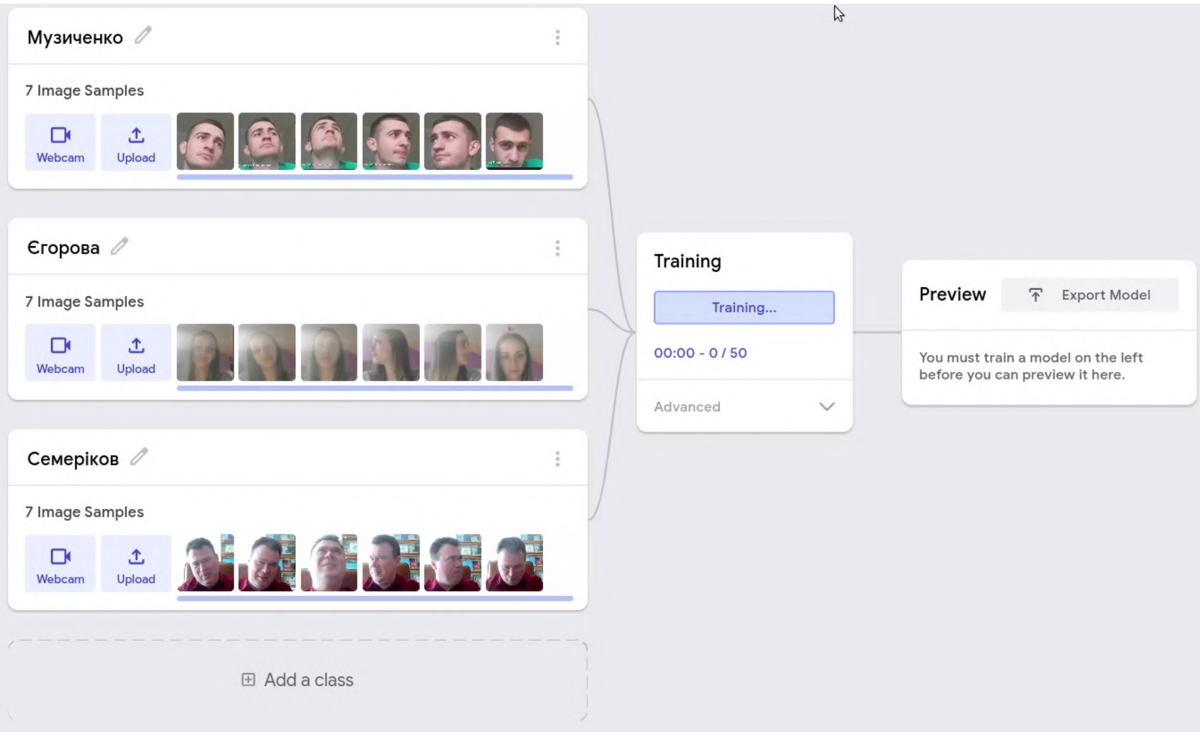

Figure 12: Distribution of images by class.

For each image class, there is a probability that a particular image belongs to that class. Students can configure additional training parameters, such as the number of iterations and the model's learning speed.

Next, we move on to training the model – at this stage, all images are converted to the corresponding numerical tensors. The last step is to experiment by choosing images of different people (not just the participants in the experiment) and discussing the recognition results (figure 13).

5.3. Integration of custom models

The libraries included in Teachable Machine are based on TensorFlow models: MobileNet for image classification [120], Speech Commands for sound classification[121], and PoseNet for body pose classification [122].

Accordingly, the built face classification model can be exported and used the same way as the previously used models of facial landmarks and hand pose.

Clicking the `Export Model` button allows you to export in various formats:

- TensorFlow.js – placement of the model at https://teachablemachine.withgoogle.com/models/[...] or downloading the model and the JavaScript and p5.js code (figure 14);

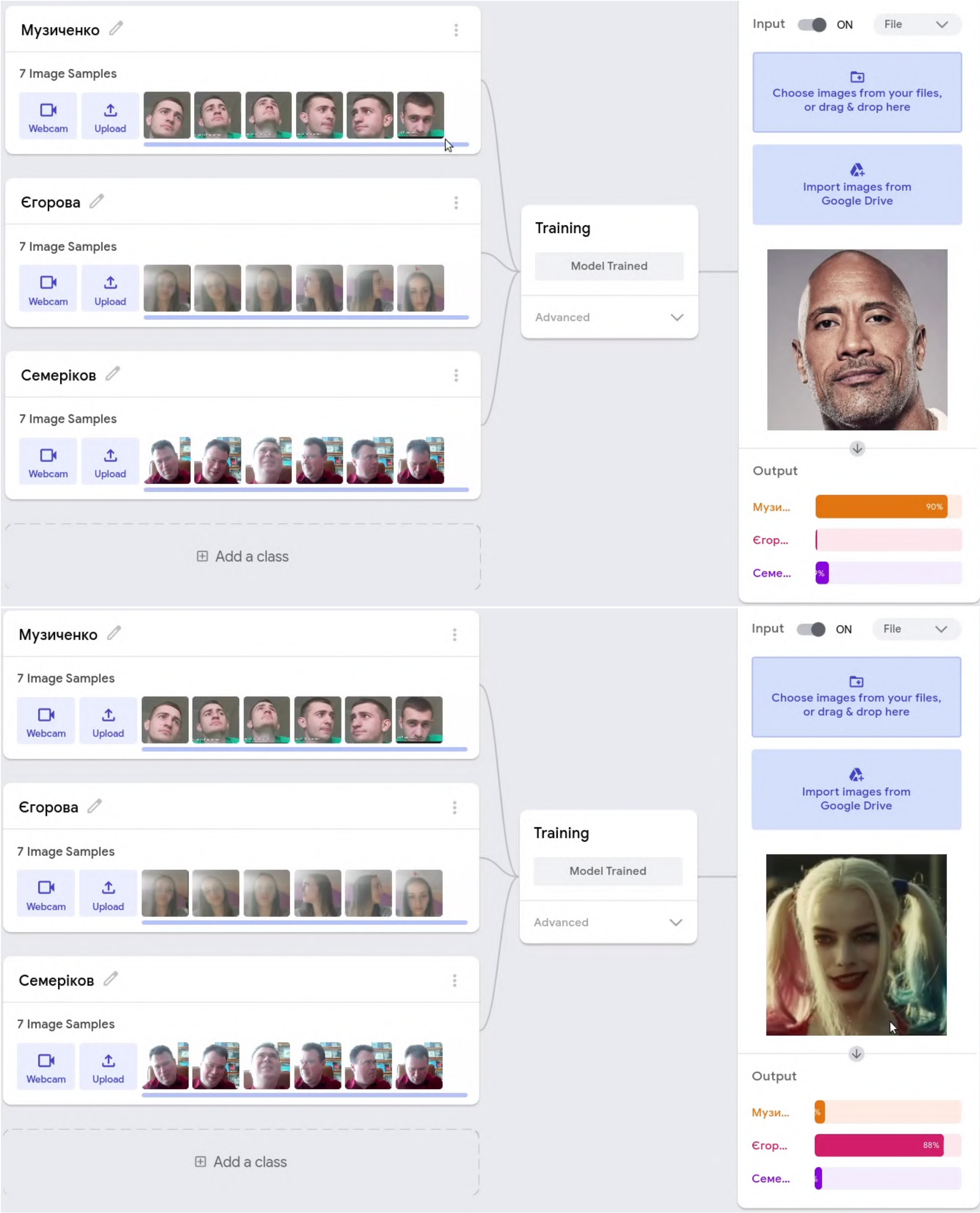

Figure 13: Results of the image recognition model.

- TensorFlow – download Python code and model in h5 (Keras) and Savedmodel (TensorFlow) formats;
- TensorFlow Lite – downloading a model in tflite format for IoT devices based on Android and Coral.

The archive with the model for TensorFlow.js contains three files:

- `metadata.json` – a text file in JSON format containing information about the version numbers of

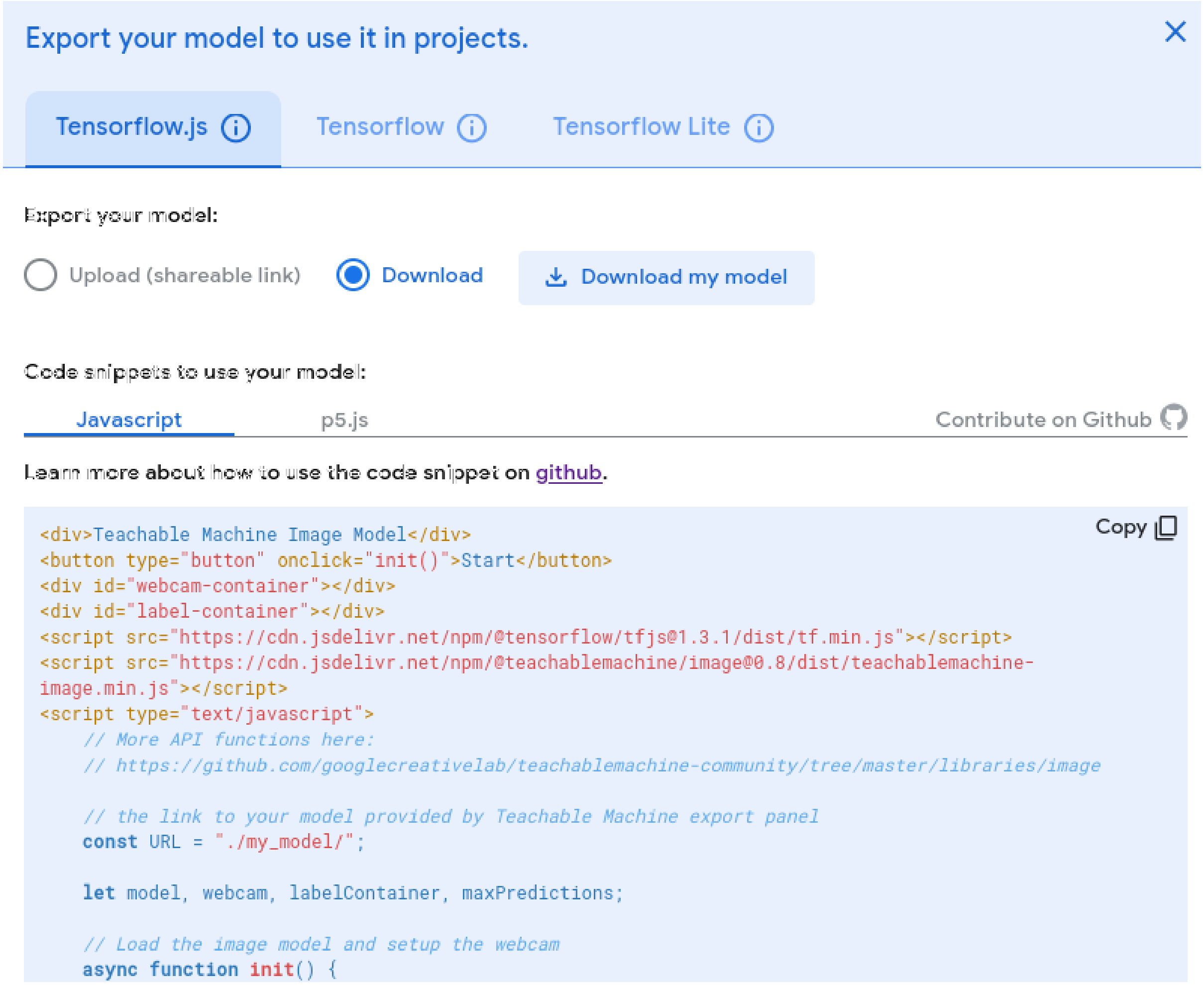

Figure 14: Exporting the model for TensorFlow.js.

TensorFlow.js (`tfjsVersion`), Teachable Machine (`tmVersion`), libraries from the Teachable Machine (`packageVersion`) and its name (`packageName` – in our case, it is `@teachablemachine/image`), date of creation (`timeStamp`) and model name (`modelName` – by default `tm-my-image-model`), image size (`imageSize` – all images are resized to the same size) and categories (`labels`) used for data labelling;

- `model.json` – a text file in JSON format containing information about the neural network architecture (`modelTopology`);
- `weights.bin` – a binary file containing the weighting coefficients of the neural network.

When exporting models, a test code is offered to verify them, from which you can learn how to connect the `tmImage` library and load the model by calling `load`, the parameters of which are the paths to the model architecture and metadata files – `model.json` and `metadata.json`.

After loading the model by calling the `getTotalClasses` method, you can determine the number of categories that the model will distinguish – in our case, this value, stored in `maxPredictions`, is three.

Just as before, every tenth frame is passed to the model for analysis by calling `predict`, which returns an array of two objects containing information about the category (`className`) and the probability that the image belongs to it (`probability`) – a string with information about them and is visualised.

From figure 15, we can see that the image on the left is identified correctly despite the change in the background compared to the training set (figure 12), while the image on the right is identified incorrectly.

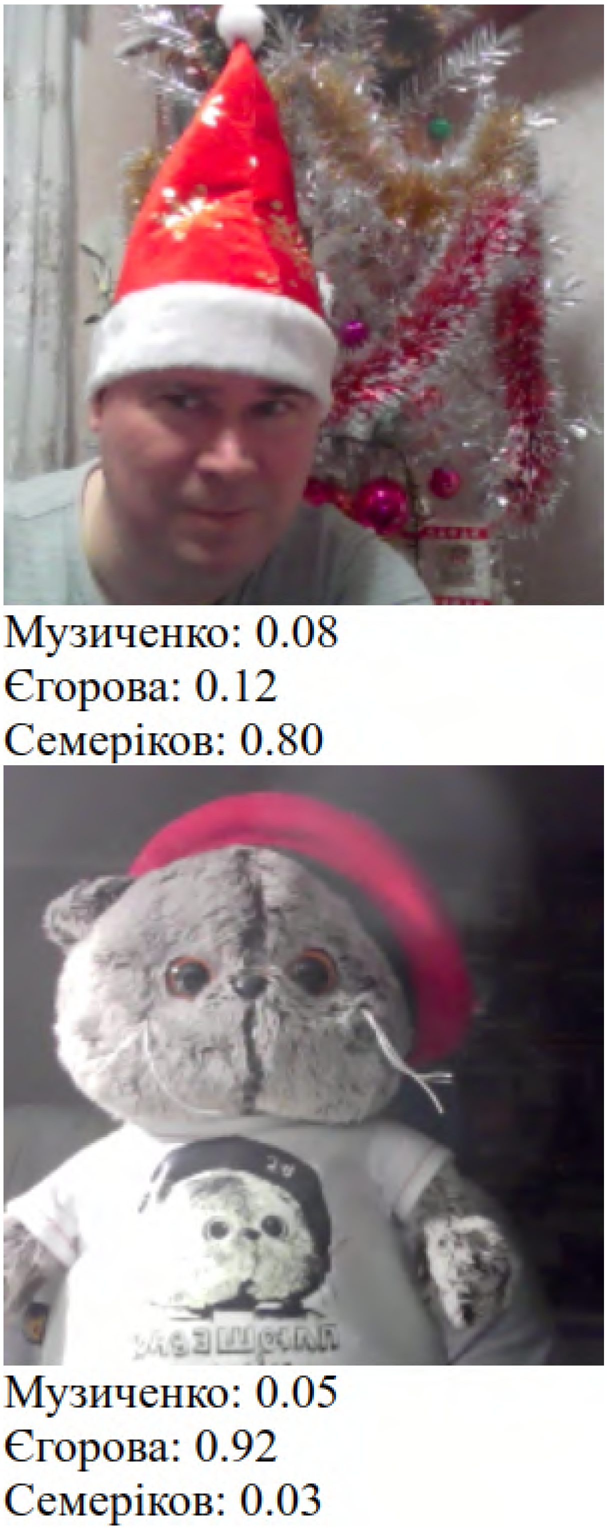

Figure 15: Implementation of face recognition.

6. Conclusions

The completed solution to the problem of developing a methodology for teaching the development of augmented reality for the Web with integrated machine learning models made it possible to draw the following conclusions:

1. The bibliometric analysis of sources from the Crossref (19 documents in 2017-2022) and Scopus

(93 documents in 2001-2023) databases made it possible to identify the main concepts of the study, grouped into 4 clusters:

a) The first cluster connects the *basic concepts of augmented reality in education*: augmented and virtual reality with education (including medical education) and human learning, including the use of smartphones;
b) The second cluster links the *concepts of learning environment design*: teaching, engineering education, computer-aided instruction, e-learning, students, mobile learning, learning environments, user interfaces, education computing and curricula;
c) The third cluster connects the *concepts of immersive learning environment implementation*: websites, motivation, learning systems, interactive learning environments, augmented reality applications and augmented reality technology;
d) The fourth cluster contains the concept of *distance education*, linked in the first cluster to the concepts of augmented and virtual reality and the concept of education (including medical education), in the second to the concepts of students, engineering education, education computing, e-learning and curricula, and in the third to the concept of websites.

The analysis of the distribution of concepts by the density of links and time made it possible to date the emergence of different concepts and track their development from educational applications of user interfaces to their augmentation.

2. The selected tools for developing augmented reality for the Web form three groups:
   a) fixed assets:
      - Simple Web Server provides the full functionality you need without installation needs that meet the requirements of simplicity and mobility;
      - ngrok traffic redirection allows access to a web server located behind a firewall (on a student's or teacher's computer), which creates conditions for working together remotely;
      - RemoteJS remote debugger allows you to debug JavaScript applications on mobile devices using desktop browsers;
   b) Three.js graphics library is a high-level implementation of the cross-platform WebGL display standard in JavaScript, which allows working with high-level graphical abstractions;
   c) MindAR augmented reality library allows working with natural images as augmented reality anchors and includes the Three.js and TensorFlow.js libraries – the latter is key for integrating machine learning models created with TensorFlow with WebAR applications built with MindAR.
3. In the process of developing and testing the methodology for developing WebAR applications for face tracking, the expediency of joint use of the MediaPipe Face Mesh model, a convolutional neural network that identifies 468 three-dimensional landmarks on the face, and the MindAR library, which allows to define any of them as an anchor, is substantiated. It is shown that the complete application of the MediaPipe Face Mesh model in the MindAR library is implemented in the form of a face mesh that is dynamically generated with constant geometry updates – a type of augmented reality associated with the overlay of images on all anchor points of the human face. Examples of using face meshes to create makeup effects, tattoos, etc., are presented.
4. The methodology of integrating machine learning models into WebAR applications involves mastering three main steps:
   a) The first step, *integration of standard models*, involves familiarisation with pre-trained TensorFlow.js models that can be used in WebAR applications. The article shows the feasibility of considering the handpose.js model used to determine the hand and its components, demonstrates the main problem of WebAR – a significant performance drop when applying the model to each frame, and suggests a way to solve it. As a result of the first step, a WebAR application for gestural size control is created and the position of the virtual object;
   b) The second step, *custom model development*, involves creating and training your TensorFlow models using the Teachable Machine, which allows you to build models to solve problems of image, sound, and pose classification;

c) The third step, *integration of user models*, is performed by exporting the face classification model built with the Teachable Machine and modifying the WebAR application developed in the first step: we load our model, determine the number of categories it will classify, and the object of augmented reality is information about each category and the probability that the webcam image belongs to it. The latter provides an opportunity to discuss the issues of classification errors and their dependence on both the settings of the model training parameters and the way the test images are presented to the WebAR application.

This study does not exhaust all the components of the problem, and further research is needed:

- history and prospects of WebAR development in education;
- a methodology for the joint use of different neural network modelling environments;
- development of WebAR libraries, in particular, in the direction of implementing ubiquitous augmented reality;
- the relationship between real and virtual in training in the context of a pandemic, natural disaster and military conflict.

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Emoji as an artificial digital language: a frame-semantic analysis of perception and interpretation

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Abstract

Emoji are widely used in digital communication, but their linguistic status and meaning are not well understood. This study aims to investigate how emoji are perceived and interpreted by different groups of speakers, based on their age, profession, and knowledge of foreign languages. The study is based on an experiment that involved participants from various fields of education and other professions, who were asked to use emoji in the learning process. The study applies the concept of frame semantics to analyze the structure and semantics of emoji signs, and to explain the variation in their perception and interpretation. The results show that emoji are an artificial digital language that exhibits both a priori and a posteriori features, and that their meaning depends on the speaker's mental frames, which are influenced by their professional activity and experience. The study also reveals the differences between representatives of the humanities and social sciences, and representatives of sciences, in their use and understanding of emoji. The study suggests that emoji have both advantages and disadvantages for the educational process and for the digitalization of society in general.

Keywords

emoji, artificial language, digital communication, frame semantics, perception, interpretation

1. Introduction

Computational linguists (Anber and Jameel [1], Annamalai and Abdul Salam [2], Brody and Caldwell [3], Chichón and Jiménez [4], Schmidt et al. [5]) have explored the idea that emoji is a promising medium for pedagogical communication. Evans [6] argues that emoji have a great potential in conveying the meaning and the emotional nuances of the phrase [7]. In the context of modern globalization and digitization, which affect the philological sciences as well, the use of visual elements in messages has become a norm. This has changed the approach to interpret many of the problems of text linguistics. Recently, researchers have started to investigate the methods of transmitting and receiving information using semiotically complex or creolized text. We define *semiotically complex text* as a non-linear (palindrome in form and perception) text, whose content can be expressed by one or more visual signs. This type of text refers us to pictographic and hieroglyphic writing, which is characterized by an emphasis on visual reading of the content.

However, we should note that the digitalization of the traditional text with the help of ICT introduces a new communicative barrier – the problem of sign interpretation. In our article [8] we presented the technology of visualizing the text of fiction (poetry) using emoji symbols on the Emoji-Maker platform. During the research we concluded that such an emoji ICT experiment stimulates students' thinking, develops creative attention, and enables them to succinctly reproduce the meanings of poetry [9]. However, we also encountered the aforementioned problem of sign interpretation, since the generation of a visual sign involves the mental frames of a person, which depend directly on the genetic structure of thinking. This, in turn, leads to the fact that not only the perception but also the generation of the

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sign will have differences (geometric shape, color, emotion, association). Makhachashvili and Bakhtina [10] consider this problem through the lens of L. Wittgenstein's hypothesis about individual language ("Sprachspiel"): "Note that the human brain copies the structure of only one language (genetic), despite knowing two or more foreign languages. Therefore, if people communicate in one language, it does not mean that they reflect the structure of the symbolic system of communication. Genetically (mentally – in L. Wittgenstein) they structure and, accordingly, perceive and interpret the text differently. And this difference occurs due to the neural network formed in the structure of genetic language in the human brain" [10].

This digital technology is very relevant for the field of philological communication today, and we believe that the further development of text visualization technology will facilitate the effective learning of fiction by philology students. However, we think that it is important to pay more attention to the problem of sign interpretation, because it affects the level of understanding among humanity in a global sense. Therefore, after conducting an experiment with students generating visual text based on fiction [11], as reported in our article [8], we carried out another experiment. Its goal is to identify the features of posteriori construction of an artificial sign in digital communication, depending on the perception of both students and teachers.

The objective of the paper. Systematic analysis of the empirical method in the study of interpretation of the visual emoji sign during its generation and perception, which will trace the semiotic transformation in the analysis of transgression of signs from natural languages into digital artificial (a posteriori) ones, especially emoji. Determining the pedagogical perception of the visual sign is made possible by the fact that the experiment involved not only teachers and students of philology, but also representatives of various fields: historians, economists, programmers, mathematicians and others, which allows to compare perceptions and interpretations of artificial emoji.

First of all, let us explain what we mean by the aposteriori nature of artificial languages. We follow the definition given by Piperski [7] in his work "Construction of languages: from Esperanto to Dothraki", in which he distinguishes between a priori and a posteriori artificial languages: Most early artificial languages were created by philosophers and had an a priori nature; this means that they were not based on existing languages, but were created on arbitrary principles… Beginning in the XIX century, artificial languages were usually a posteriori, i.e. they were partly derived from existing languages…‘' [7]. However, we consider emoji language as a hybrid of apriori and posteriori types, because it originates in the computer being (hereinafter – CB) – a complex, multidimensional field of synthesis of reality of human experience and activity mediated by digital and information technologies; technogenic reality, a component of the technosphere of existence [12]. Thus, like a priori languages, emoji is classified as a logical language (loglang) – a programming language. This dual nature is due to the fact that emoji was first created by a Japanese designer Shigetaka Kurita [13], who designed the first 176 characters for Japanese users of the i-mode mobile platform. The pictures he created (12x12 pixels) reflected the lives of the inhabitants of his city (Gifu Prefecture, Japan), reproducing the most common discourses of real communication. Therefore, drawing on the idea of manga – one of the forms of Japanese art, Kurita depicted pictographically elements of Japanese culture, and the phonetic similarity of the word emoji was coincidental. Only later in Unicode Consortsium emoji acquired the meaning of emotional characteristics.

In our study [9] we emphasize the role of the reader-interpreter, which led us to the following conclusion: recipient (reader-interpreter), using specific technological tools, a visual iconic sign (smile) reproduces the polylateral metalinguistic functionality of the meaning of the sign based on the artistic word. The results, on one hand, complicate the structure of semiotic field of artificial sign, on the other hand – expand mental frames of human thought, explicate the emoji sign as universal rather than local or mental (the latter, in turn, is confirmed by the fact that, once adopted by the Unicode Consortsium, emoji transgressed into the international language of characters, whose creation has become purely digital). Universality and digital conditionality of emoji provide multi-directional semantic load of the sign. Addressing this issue, Makhachashvili and Bakhtina [10] introduced the linguistic concept of "polylateralism" – (from the ancient Greek $\pi o \lambda \acute{\upsilon}$ – many; from the Latin latus – side) – a category that reflects in the digital emoji sign versatile, multi-vector reproduction of emotions through logical-structural, lexical-grammatical, morphological, etc. means [10].

Therefore, based on the logic (a priori) and a posteriori aspects of the artificial digital emoji language, and building on previous research on this topic, we propose the design of the pedagogical experiment. We aim to examine how emoji is used in the learning process through digital communication, what criteria are used by educators and learners when constructing an artificial sign, which plays a special role in the interpretation of a specific emoji.

2. Research methodology

To solve the delineated tasks, the following methods were used: analytical review – for the study and analysis of scientific and methodological literature, curricula, generalization of information to determine the theoretical and methodological foundations of the study; pedagogical modeling – for the study of pedagogical objects through the modeling of procedural, structural and substantive and conceptual characteristics and individual "aspects" of the educational process. Empirical method – in order to study the phenomenon through experiment and rational processing of the obtained data. Structural method – in order to identify and analyze structural elements, individual components, categories, etc., which form the emoji-sign. The method of component analysis – in order to identify the minimum semantic (semantic) elements that form the semantic component of the sign. Semiotic method – in order to study the sign from the standpoint of its organization, the properties of its elements and categories. Descriptive method – in order to describe in detail, the language units in the inventory and systematization. Dialectical method as a way to find a theoretical construction of the linguistic picture of the world, the study of the true criteria for the coexistence of language and the world, language and man, language and machine. Logical-analytical methods, namely the method of induction and deduction, which allows to consider the content of the object, specifying and generalizing its concept; the method of formalization as the study of an object by reflecting their structure in symbolic form.

3. Research results

In order to identify differentiation in the interpretation of emoji, we conducted an experiment involving 110 respondents aged 10 to 70 years (figure 1). Such a large-scale coverage of the age category allowed to fundamentally reflect the picture of the world and digital literacy of mentally different representatives, and also allowed to distinguish groups of people whose linguistic pattern differs significantly from respondents of other age categories. All this is directly reproduced in the interpretation of the optical digital sign. Thus, the results of the experiment show that emoji is used more by respondents whose age range is from 10 to 20 years, and to a lesser extent – from 40 years (figure 2). Accordingly, such results explain the verbal skills of the recipients, depending on the professional and mental qualities, which will be discussed later.

Since the experiment was conducted in order to identify functioning of digital emoji language in the pedagogical process, divided into various narrow fields, the part was taken by representatives of the following professions: philology (educators (lecturers, teachers) and students). However, the validity of the experimental field increases due to the participation in the experiment of representatives of the following fields: history, IT, mathematical modeling, publishing, choreography, psychology, economics, diplomacy, archaeology, IT, fine arts. The status of the respondent varies from student to habilitated doctor. The wide scale of profile differentiation fractalizes semantic shifts in the interpretation of a sign in more detail. This is characterized, in addition, by the choice of social network, where the respondent uses emoji (figure 3). We can see that most age groups of recipients use Facebook, Instagram, Twitter (X). However, the age group of up to 20 years tests artificial languages on other platforms (Tik-Tok, Discord, Tumblr), which is also reflected in the verbal skills of the recipients. In terms of professional affiliation, Facebook is more used by the teaching staff of various universities (59.1% of respondents); Instagram – by students of different universities – 67.3%, other social networks – by the lowest percentage of respondents, which is fractalized to all categories of respondents.

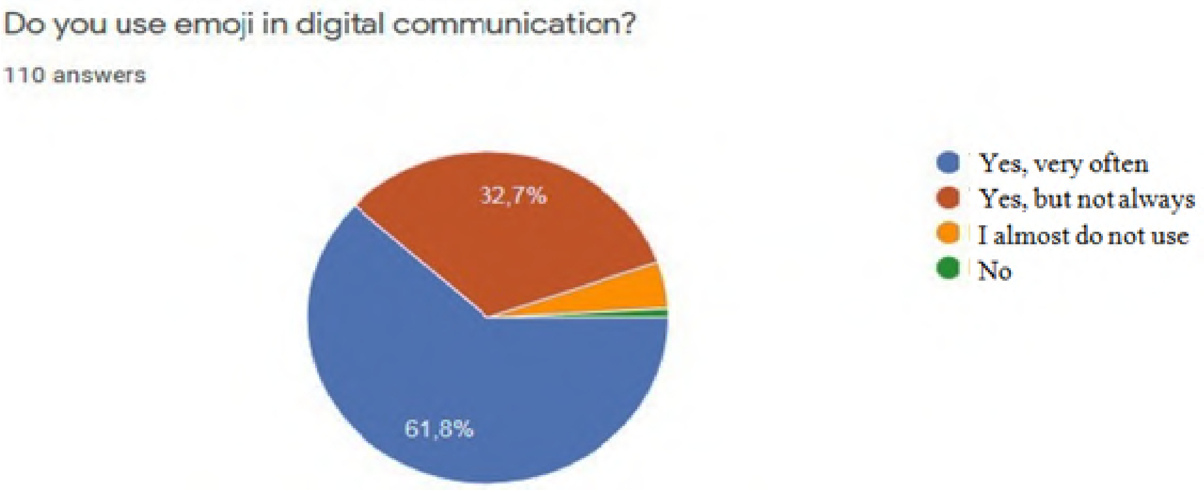

Figure 1: Frequency of emoji usage in digital communication.

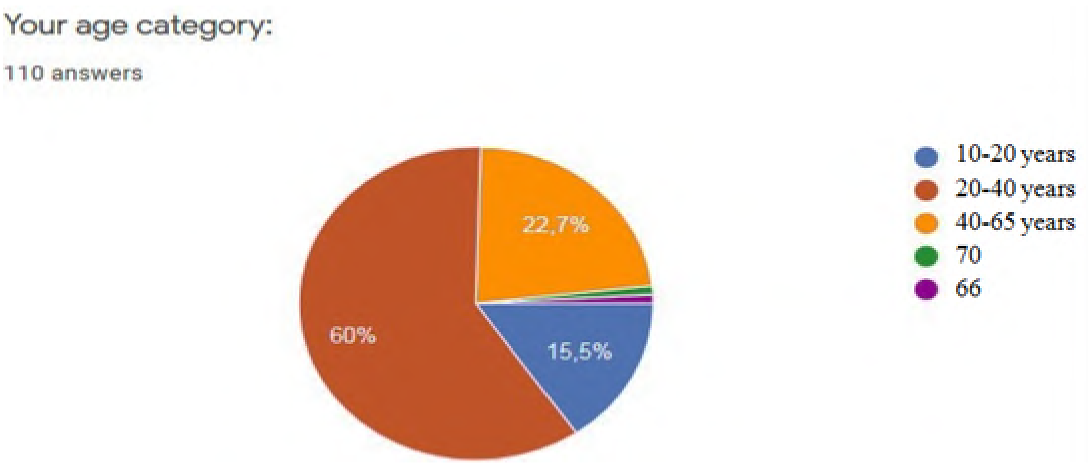

Figure 2: Age brackets for emoji users in digital communication.

Another important characteristic of differentiation and fractalization of answers is mastery of foreign languages. Among the respondents were experts in the following languages: Russian (99%), English (98%), Spanish (74%), Italian (49%), French (49%), German (23%), Chinese (4%), Japanese (2%), Korean (1%), Czech (1%), Polish (1%), Georgian (1%), Armenian (1%), Hebrew (1%), Turkish (1%). Therefore, the results concluded that the use of emoji in digital communication (both in everyday life and in the professional sphere) is more pertinent to recipients with knowledge of two or more foreign languages (table 1). However, the interpretation of a particular sign varies and depends on a particular foreign language (and / or on professional skills). Emoji is a typical visual complement to the content of text / speech in digital communication for experts in Oriental languages, including Mandarin Chinese, Japanese and Korean, which, in turn, refers us to the mental frames of Oriental language structures. Fillmore [14] classifies frames as P-semantics, which operates with the concept of interpretive description of the semantics of tokens, grammatical categories and text. Such semantics includes three components: compositional semantics (frame structure of the text), practical reasoning based on the use of frame knowledge (knowledge of reality) and provides identification of implicit semantic connections between utterances in the text; reasoning based on knowledge of communicative intentions represented in frame form. In the situation of reasoning, natural-linguistic inference is considered as a set of operations on the elements of frames [14]. Reliance on the frame structure also applies to experts in the Spanish language (74%). However, it's worth noting that in Hispanic communication emoji has emotional presupposition: Spanish language professionals a priori interpreted emoji of a psycho-emotional

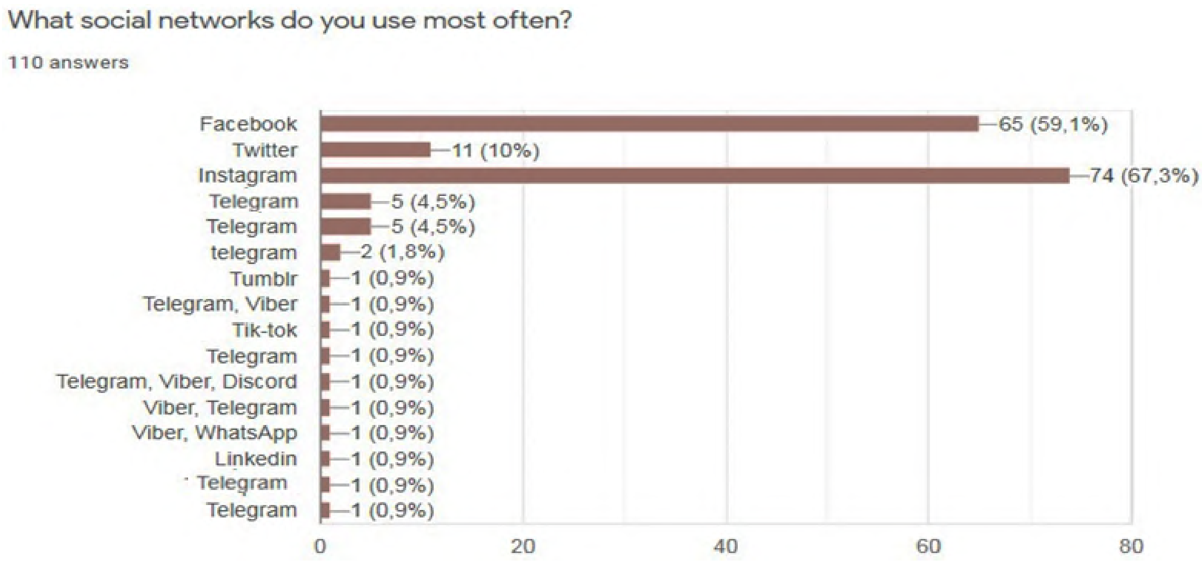

Figure 3: Choice of social network, where the respondent uses emoji.

meaning, mostly adiaphorizing rational structure components of the sign. The positive attitude and use of emoji is also observed in the professional specifics, in particular, artists who, unlike experts in Romance languages, appeal to real causal (implicit and semantic) connections both between utterances in digital communication (emoji) and between components of one sign.

Table 1
Distribution of native languages spoken by emoji users.

What languages do you speak?	% of respondents
Ukrainian	100%
Russian	99%
English	98%
Spanish	74%
Italian	49%
French	49%
German	23%
Chinese	4%
Japanese	2%
Korean	1%
Czech	1%
Polish	1%
Georgian	1%
Armenian	1%
Hebrew	1%
Turkish	1%

The most unexpected among the results of the survey were the responses of computer science specialists, whose attitude to emoji was twofold. However, we can assume that experts in the field of IT completely include emoji in the loglan, which apriori cannot have an emotional substrate. Computer science specialists, in turn, perceive not so much a language as its matrix. Under such conditions, the logical indicator is that the most extensive use of emoji is in the humanities (philologists, historians, philosophers), the specifics of whose profession refers to information as a tool of influence, which is directly inferred from the emotional substrate. To a lesser extent, emoji is used by the exact sciences specialists, the results of whose activity are represented by numerical data. The smallest percentage – computer science specialists, where the result is a matrix. The same effectiveness, as in the above case, applied to the interpretation of the concept of emoji (table 2). Artists and / or Oriental and Romance languages professionals emphasized the iconicity / ideography of the sign in digital communication, the graphic visualization of which is independent of the narrative form, but performs the contractual function of an auxiliary non-verbal explicant. Specialists in the humanities focused on the emotional characteristics of the sign, which is designed to enhance the effect of the communicative act in digital medium.

Table 2
Interpretation of the concept of emoji by respondents.

How do you understand what emoji is?	
Emoticons	Facial expressions in social networks
Emoticons	A kind of graphic language
Emoticon	Mood display
Smileys	Face sticker to emphasize or express your emotions in the message
Expressing emotions with pictures	The language of various graphic signs
Small pictures used to indicate emotions	A picture that reproduces feelings, understandable to both the recipient and the author of the statement
Signs	A graphic sign, an illustration that conveys a certain concept, is used when communicating online
A symbol for conveying the emotional side of communication	Psychological state that reflects the instantaneous reaction to external factors
Graphic symbol for emotions and states	Coloring of the written text and accessible expression of emotions
A picture depicting a certain emotion	Emotions that help to convey more clearly our emotions, state, attitude to the situation, feelings, and sometimes due to emotions you cannot even write a text.
Emoticons designed to facilitate communication and convey different states / emotions	Mini drawings to indicate emotions, objects through which it is possible to convey information
Expression of emotions with the help of visual images	Use of digital symbols to demonstrate emotions, feelings, personal reaction to messages, photos in online communication
A picture that helps you show your own emotions in text messages	Auxiliary ideographic record

We mentioned above the verbal skills of the recipients, which, like the previous features, depend on age, professional activity and knowledge of foreign languages. In order to trace the differentiation of the perception and interpretation of the emoji sign, 10 most used emoji in different operation systems and digital platforms were added to the survey in order to trace how the respondent understood each sign. In addition to the characteristic of popularity, the dual or polylateral nature of the sign was an important factor in choosing emoji for the experiment, which hypothetically refers to the conclusion about the differentiation of the perception of signs by each recipient. Thus, the sign #1 (figure 4) for 99% of respondents is interpreted unambiguously, with deviations of the semantic load in 1%: ok, good, cool, great, well done, good job, very good, super, perfectly etc. However, from recipients aged 10 to 20 we have answers that reflect age-related deviations in perception, for example, “I like it (smiley is not very much, my grandmother throws me and teenagers use for this 🙂)”.

A similar perception applies to the sign #2 (figure 5), the interpretation of which is 100% synthesized with a negative connotation and explicated within one semantic field. However, given the scale to differentiate the characteristics of respondents, the verbal definitions of the sign can be traced to the structure of the linguistic ousia of answers, hypothetically deducing the nature of the category / profession / status / experience of a particular answer (table 3).

The sign #3 (figure 6) in digital communication embodies the polylateral structure of perception and interpretation. The answers to this sign are radically different (table 4).

Perception and interpretation of the sign varies within the concepts of “horror”, “shock”, “fear”, “surprise”. Accordingly, it will be appropriate to emphasize the characteristics of the recipient to trace

Figure 4: Emoji sign #1.

Figure 5: Emoji sign #2.

Table 3
Generalized definitions of Emoji sign #2.

What does the following emoji mean to you?	In what context could you use it?
Surprise	Means surprise, used as a reaction to a message, be it a photo, video or news
Shock	When I realized that 1 course had already ended
Oh really!	You can go crazy, but really
Wow	Surprise. Hidden irony (rare)
To indicate surprise / astonishment, but mostly with a positive connotation	Incredible!
Surprise, admiration	Surprise from the written (description of actions in the message)
Horror! Shock! What is happening!	Surprise from the situation or from the words spoken

the frame structure of speech and verbal skills of respondents. Thus, the sign #3 is interpreted and perceived as horror in the category of 20 to 40 years (60%), shock – from 10 to 20 years (15.5%), fear – from 40 to 65 years (22.7%), as well as 66 years (1%) and 70 years (1%), surprise – from 40 to 65 years (22.7%). According to professional characteristics, the answers are fractalized into all categories evenly.

The situation with the sign #4 is more unambiguous (figure 7). However, it should be noted that the age categories 10 to 20 and 20 to 40 years in most cases interpreted the sign in terms of CB exclusively, emphasizing the digital continuum, in contrast to other categories that described the sign purely emotionally in the real ontological dimension (table 5).

The sign #5 (figure 8) expresses an error in interpretation and perception of 2%. Among the most typical – "sadness", "tears", "sadness", "fiasco", "pain". The sarcastic connotation of the use of the sign in digital communication (age category from 40 to 65 in the humanities) (table 6) has to be emphasized, as well as despair, depression, fatigue (age category 10 to 20 years – students) – with appropriate explanation by the recipients of their interpretation and perception: term finals at the university).

The sign #6 (figure 9) is identically interpreted and perceived by the respondents, but there is a

Figure 6: Emoji sign #3.

Table 4
Generalized definitions of Emoji sign #3.

What does the following emoji mean to you?	In what context could you use it?
What a horror!	Omg! Strong surprise with hints of feelings for the interlocutor
Stupefaction	Horror; surprise in a negative context
Cannot be	Madre mia! in a bad way
"Horror" – wrote a work on one topic, and it was necessary on another))	Drip! It is too much! I'm shocked!
Horror! / Reaction to something very unpleasant	Oh my God!
To indicate surprise / shock, but not only with a positive connotation. Sometimes as a synonym for the expression "Oh, only!"	Reaction to unexpected news, surprise
Oh no! What?	Something fascinating
People are good, the house is white	Surprise. Negative or jokingly negative context.

Figure 7: Emoji sign #4.

differentiation in the verbal reproduction of the sign. Thus, respondents with an age category ranging from 10 to 20 years, as well as specialists in Germanic languages have the signification "*kiss*"; from 20 to 40 years (respondents of the humanities) – "*flirtation*", "*love*", and respondents of exact sciences – "*Air kiss*", "*I kiss and love*". "*You are very dear to me*". Respondents between the ages of 40 and 65 provide a more detailed lexical field, giving the signifier an explicit character: "*You are my good, thank you. A sign of support, gratitude, approval, support*". The results showed that such an explication would be more typical for teachers with sufficient experience in educational institutions, mainly in the humanities. It is noteworthy that IT professionals do not visually perceive the sign for two reasons: 1) this symbol can be used only with the close social circle; 2) visually do not like the symbol. This perception once again concludes the structure of thinking of specialists in the exact sciences, the result of which is a number / calculation / matrix.

An ambiguous picture is observed with the sign #7 in digital communication (figure 10), because

Table 5
Generalized definitions of Emoji sign #4.

What does the following emoji mean to you?	In what context could you use it?
Love	I really like it, I support it very much, thank you very much
I like something	I like you
I love you!	Support, admiration
Wonderful	"Magical!" (positive warm attitude, especially to something sweet, sweet)
"With love" – especially a warm relationship, thank you	What I see is beautiful
Fascination with news / comments from a close person / child / friend	When I saw the puppy
See something cute, beautiful	Friendship compassion
Fascination with news / comments from a close person / child / friend	It has many meanings: it conveys pleasant amazement, joy, admiration for beauty, love

Figure 8: Emoji sign #5.

Figure 9: Emoji sign #6.

according to previous experimental empirical data, it was stated that the sign has a latent negative connotation. In order to confirm or refute the station, the mentioned sign was placed in the questionnaire. The results showed a proportion of 60/40: 60% of respondents, whose age category is mainly from 20 to 40 (23%) and from 40 to 65 (37%), perceive and interpret the sign, emphasizing the neutral and / or positive connotation that explains approval of something ("okay", "good", "super", "yes" etc.). However, 40% of respondents (mostly humanities students – age group 10 to 20 years, as well as representatives of creative professions – artists, writers) see in the sign a negative connotation, which is characterized by several expressions: either sarcasm, or contempt for the interlocutor, or attempt to maintain one's opinion (table 7).

It was experimentally interesting for the authors of the study to trace the emotional characteristics of the sign #8 (figure 11).

Undoubtedly, the sign is an identifier of the global civilizational phenomenon of modernity, which led to the global pandemic – the coronavirus in COVID-19 [15, 16, 17]. Specified sign, in fact, with appeared

Table 6
Generalized definitions of Emoji sign #5.

What does the following emoji mean to you?	In what context could you use it?
I'm crying	When I want to emphasize my fatigue from something, irritation, helplessness
Very sad	Difficult situation
Sadness / crying	Sorry, pain, injustice
Tears, sadness, can be sarcastic	Notification of bad news, reaction to something sad
"Sorry" – disappointment, sadness	I forgot to attach the file to work
Disappointment when something failed, but this smiley still has a humorous connotation. In my opinion, it cannot be used as a reaction to the news related to the deterioration of human health, or, God forbid, death.	Something tragic
frustration in life	"but not what the stars are so united, I will not give up" + hyperbolization of real disappointment
frustration in life	When something is difficult / impossible to change, but I would like to.
sadness or tears with irony / sarcasm (any context)	Personal correspondence or friendly, reaction to the message

Figure 10: Emoji sign #7.

Figure 11: Emoji sign #8.

in digital communication usage at the beginning of the quarantine, which covered virtually the whole world. However, computer being eliminates any locality, leaving in the substrate a psycho-emotional factor of sign perception. Thus, according to the results, we obtained the following disclosure: 70% of respondents of all categories explained the sign as "disease", "epidemic", "temperature". However, the answers of humanities teachers, as well as students aged 20 to 40, were typical. The signifier of the #8 sign of the mentioned respondents is "silence" or "I do not use". Representatives of exact and natural sciences mostly emphasized that the sign does not belong to their digital continuum (table 8).

The sign #9 (figure 12) is not characterized by popularity in use in computer being, therefore a priori

Table 7
Generalized definitions of Emoji sign #7.

What does the following emoji mean to you?	In what context could you use it?
Like	Keep it up, super
Super	Short answer to the sign of approval, support, acceptance of information
OK	Very good, or sarcastic
"good idea"	"approval" (neutral)
Well done! – approval	Means that the above seen cool (accompanied by other emojis can mean causticity, on the bag, generally expressing both good and evil)
Well done / class! / Great job! / OK	Approval of user message (actions described in message)
Class, great, thanks! All is well! Most likely, it is a response / reaction to someone's fulfilled request or reaction to the news and carries approval, or sometimes this smiley is a neutral response.	Again, it can mean either satisfaction and approval, or I use it in an ironic sense
postironia	good job; consent

Table 8
Generalized definitions of Emoji sign #8.

What does the following emoji mean to you?	In what context could you use it?
Quarantine	Warning or description of the current situation
I'm sick	I'm in a mask)))
I do not use	Mask on the face, silence
Coronavirus	Wearing a mask is mandatory, something related to the hospital
Laughter under a mask	COVID-19
I'm sick. But I would call such an emoji would not use	Self-isolation
I'm silent	Limitations of opportunities
I'm silent	I'm sick or I'd better keep quiet
She fell ill. But in the conditions of quarantine - observance of safety rules.	Someone is sick and has to SIT AT HOME. (obvious influence of recent events)
Keep your distance	I would have written earlier: I can't speak! now it is possible: we adhere to a mask mode. Didn't use this emoji.
Safety measures during the epidemic	I do not use this, but now it is relevant, fashionable to use as a reminder of protection

it was placed for the purpose of revealing of differentiation of a lexical field of respondents that is projected on perceptual sensations.

A remarkable point is that the less popular (almost unknown emoji sign) was 100% interpreted unambiguously and with one (in this case – negative) connotation. This is important information, because popular characters have many semantic branches in recipients of different categories, which again confirms the open aposteriority of artificial emoji language with the emergence of new connotations in digital communication and expansion of the lexical field of the respondent (table 9).

The sign #10 (figure 13) in our experiment is the key optical sign in digital communication.

The sign is quite popular, however, as the results of the experiment showed, it is popular not for the denotation, but for the psycho-emotional characteristics of the respondent. 99% of respondents answered that the sign has a negative connotation and optically reflects the state of anger, rage and rage. In fact, this sign is mental in location – a sign of Japanese origin to express a sense of triumph (in Unicode Consortium – "Face with Look of Triumph"). Thus, we conclude that the mentioned mental

Figure 12: Emoji sign #9.

Table 9
Generalized definitions of Emoji sign #9.

What does the following emoji mean to you?	In what context could you use it?
Head turn	In alcohol intoxication
tired, broken, confused	This is my face every morning
Amazingly	I do not use it because it is disgusting
incomprehension	An unusual, extraordinary situation; uncertainty
"Hangover" / "sleep deprivation" – a reaction to questions about the condition	Expresses stupidity, play, intoxication
Fatigue, inability to concentrate	Confused
condition of students after the session	Crazy situation
I don't even know. when I swelled dumplings...	I have never seen such a thing, he is a bit drunk

Figure 13: Emoji sign #10.

frame was not read by computer science specialists, artists or connoisseurs of oriental languages. The sign was interpreted and perceived according to the universal psycho-emotional state – the state of anger, rage, anger (table 10).

The respondent who provided the only correct answer is a historian by profession. Hypothetically and deductively, we can conclude that in this case the emotional nature of the artificial language emoji prevailed, which, in fact, is one hundred percent embedded in the concept of Unicode Consortium. Correct disambiguation of this sign is an exception to appeal to the respondent's profession when it comes to text as information. For linguists the text was perceived as a structure for computer science specialists – a matrix, representatives of the exact sciences – hypothesis. Perceiving the text as information, the representative of the historical profession did not notice the emotional nature of the sign, relying in general on the information about this sign, which is its (sign) English name "Face with Look of Triumph".

The final stage of the survey was the question "Can emoji replace natural language?". In fact, the last question is an additional result of previous conclusions on the use of emoji in the pedagogical process, depending on the different categories of respondents. The results of the survey show the following picture: 5.5% (6 respondents) answered "Yes, in full"; 29.1% (32 respondents) – "50/50"; 59.1% (65 respondents) – "No, they can't" (figure 14).

Table 10
Generalized definitions of Emoji sign #10.

What does the following emoji mean to you?	In what context could you use it?
Malice	Lots of work, boring, maybe annoying
Malice	“evil”, “dissatisfied”, “not in humor”, “offended”
I’m angry	I’m outraged
Fatigue	I would kill!
Very emotional	Horror
I’m boiling	the last stage before anger, I can barely restrain myself from breaking
Anger, resentment, but again, I would use it to denote my reactions in not very serious situations. In addition, I read that this smiley is not an expression of dissatisfaction, but has a different connotation, but for me it is an expression of these emotions.	“God forbid she’s still something” XD (stock up on patience)
Dissatisfaction, anger, the tram was late	overflowing with negative emotions, I want to let off steam

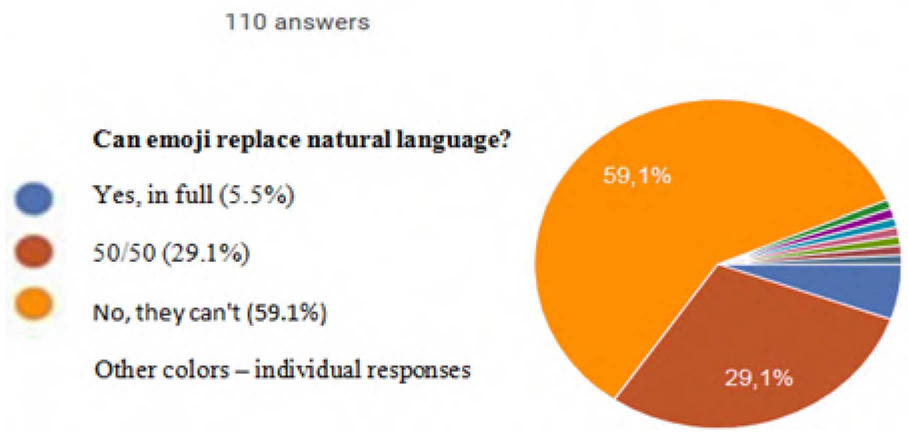

Figure 14: Interchangeability of emoji sign system and natural language.

Note that the answer “Yes, in full” belongs to the respondents, whose age category is mostly from 10 to 20 years, to a lesser extent – from 20 to 40 (students and teachers of philology and artists). In the first case, such results are explained by the nature of the humanities (mostly literary studies), where emoji is an a priori fact of the aposteriori continuum (for example, a work of fiction), and therefore is one hundred percent significant and signifier at the same time. In the second case, the object of fine art is essentially synonymous with emoji pictographic (visual, optical) result of creative activity.

The answer “50/50” belongs to philologists (linguistics), as well as representatives of sciences (economists), social sciences (psychologists), humanities (archaeologists, publishers). Philologists-linguists appeal to the nature of their profession, considering the text (including art) as a structure – in particular in syntagmatics and paradigmatics, and thus, this explains the interest in the differential verbalization of the polylateral emoji sign as an apriori-posteriori system of thinking [10]. Hypothetically, we explain the position of the representatives of economic sciences, appealing to the ergonomic ousia of language and speech resources in digital communication. In the case of the social sciences and humanities, a fundamental factor is the understanding of emoji as a supplement to the basic layer of information in digital communication.

The answer “No, they can’t” belongs more to the humanities, in particular to philologists, whose age category is from 40 to 60, as well as 66 years. This is probably explained by the temporal limits of the emergence of the digital continuum in the former Soviet republics, which in the long run prolonged the universality, ideality and completeness of natural languages.

A big surprise was the position of computer science specialists, which expresses the impossibility of artificial languages (including emoji) to be a substitute for natural. We have already emphasized this unexpectedness above. Thus, we finally conclude that computer science specialists, studying language as a digital palindrome and an atemporal matrix, classify emoji as a loglan, which a priori cannot have an emotional substrate. 7 out of 110 respondents expressed a desire to express their opinion on the question "Can emoji replace natural language?":

1. *They can only supplement / diversify.*
2. *Replace no, but they give the correspondence cool emotions. One emoji can convey your mood.*
3. *It is only a supplement to the written conversation, although it can be a substitute for emotions in the same conversation.*
4. *For me, emoji is more of a complement to ordinary language, but not a replacement for it. It's like a picture book. Without pictures it is not so colorful and fun.*
5. *They create an analog language, but natural language is better, because you can operate live with a newly created expression of emotions. Emoji create boundaries within which you can express yourself, but it is often impossible to find an exact match for your emotions.*
6. *Partly, but it is worth the vicinity ' favorites, each emoji treated every person differently. And this can lead to misunderstandings. And natural language cannot be completely replaced, it is rather a supplement to the expression of emotions.*
7. *To some extent. But some have already replaced* ☺

The respondents' detailed answers were subject to digital content analysis via an open source Voyant corpus/text mining toolkit (https://voyant-tools.org/). Two instruments were used specifitaly for 1) key words identification (quantitavely calibrated word cirrus, featuring foregrounded concepts and notions) – figure 15, and 2) key words frequency estimation (key words trending in the horizontally segmented corpus of responses) – figure 16. The key words of the respondents' detailed answers in equal proportions are "language", "emotions", "emoji", "expression", which hypothetically appeals to the conceptualiazation of natural languages as perfect, and therefore artificial languages, in particular emoji, are an optical supplement to the expression of a particular context. Consequently, emoji becomes not so much an artificial language as a form of language, a frame of writing that enhances and / or explains human feelings and emotions, but at the same time can create misunderstandings of the explication of the signifier, which depends on many factors: conditions, modality of expression etc.

Figure 15: Digital content analysis: calibrated word cirrus.

All the stated above, given the specifics of the respondents' answers, allows to conclude that in terms of expression emoji is not an independent language. Despite a clear and logical algorithm for generating and codifying artificial language in computer being, the perception and interpretation of a particular emoji sign varies depending on its use by a particular person. However, it is this feature of

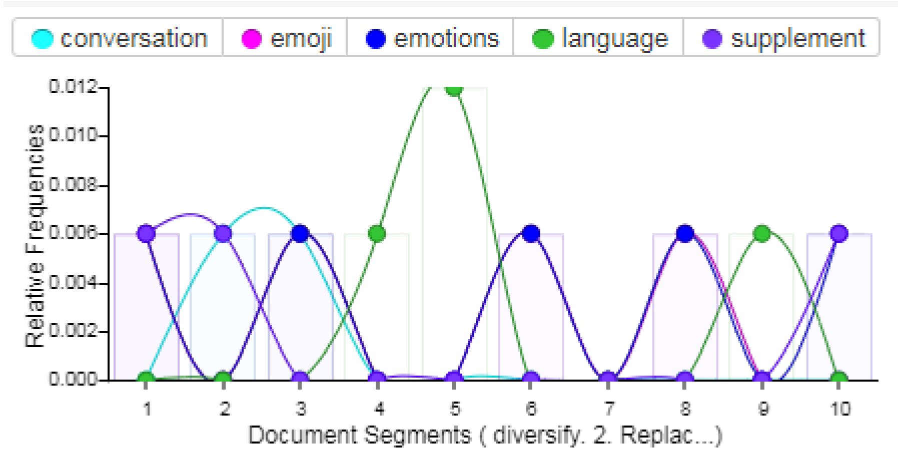

Figure 16: Digital content analysis: key words frequency.

the emoji language that involves updating the content and form of academic writing in the pedagogical educational process with the involvement of the ICT generated and implemented emoji language in a specific context. After all, the use of graphic signs will promote the development of visual (photographic) memory in students, as well as the development of emotional intelligence (EQ), necessary for awareness and understanding of one's own emotions and the emotions of others [18]. According to theory of Bar-On [19], emotional intelligence is defined as a set of various abilities that provide the ability to act successfully in any situation [20]. In addition, under lockdown through COVID-19 timespan [21, 22, 23], the use of emoji in the pedagogical process can prevent stressful situations, and therefore provide for better and more effective learning, because emotional intelligence involves the activation of the following functions: interpretive, regulatory, adaptive, stress-protective, activational.

Thus, summarizing all the empirical data collected through the survey, we can trace the effectiveness of the use of artificial languages in the pedagogical process, taking into account the specifics of the professional activities of the respondent. However, we should note that, summarizing the experimental data, we get another question: why use the emoji language in the pedagogical process? As the survey showed, emoji are an integral part of modern digital communications. Moreover, the digitalization of the educational process by its nature appeals to the codification of the semantic field of the communicative act [24]. Therefore, we consider emoji not so much a new as a newer, modernized format of the sign system, which allows different systems in its structure (cuneiform – hieroglyphics – Morse code) in digital communication.

4. Conclusions

We conducted a survey of participants in the educational process to investigate the following:

1. The artificial digital emoji language exhibits polylaterality in its structure (sign generation elements) and semantics (multi-directional perception and interpretation of the sign). This accounts for the diversity of emoji signs, which reflect both mental frames and universal features.
2. The polylateral perception and interpretation of emoji depends on the characteristics of the speaker, which we classified into the following categories in our study:
    - Age
    - Profession
    - Foreign language proficiency
    - Social network preference.

Our empirical experiment was initially designed for teachers and educators in the pedagogical field. Our aim was to examine the speed and direction of the integration of the digital continuum into the pedagogical activity (artificial languages, especially emoji) in order to assess the feasibility and effectiveness of learning at the intersection of natural and artificial languages and digital communication. However, we also received responses from other professionals, such as computer scientists, economists, artists, poets and writers, which enabled us to broaden the scope of our study, considering not only antithetical professions (humanities and sciences), but also the nature and specifics of each profession. The latter, in turn, is encoded in the structure of the speaker's thought by mental frames that shape the verbal language system and the speaking behavior of the respondents, as well as the ideographic visual pattern embedded in the artificial language of emoji.

Based on the results of the experiment, we also conclude that all respondents (110 people) use emoji in both their personal and professional lives. However, the essence of emoji in digital communication has significant nuances for each profession (not excluding age and language skills). Thus, the representatives of the humanities and social sciences use emoji to convey the psycho-emotional aspect of the sign, considering it as an addition to the text to express emotions in digital communication. Therefore, emoji can replace natural language up to 50% for these respondents, as shown by the experiment to reproduce poetic content using Emoji-Maker platform.

Only a small percentage of respondents believe that natural language can be fully replaced by artificial language. These respondents include philologists and linguists. However, it should be noted that linguists provided detailed answers regarding the perception and interpretation of emoji signs, which confirms their view of emoji language as an a priori-a posteriori system. Therefore, emoji can be either a supplement or a substitute for natural language with a complete meaning representation.

Representatives of sciences (mathematicians, economists, programmers) regard emoji as an independent language to a lesser extent, which is explained by the frame P-semantics of their thinking structure, which is as follows. For these speakers, natural language itself is an auxiliary element for their professional performance, which a priori places artificial languages in the position of auxiliary symbols to obtain the work result in the form of digital content and matrix grid. Therefore, most of these respondents use emoji without assigning clear and unambiguous connotations to the sign during digital communication.

5. Future work

For future research, we need to extend the classification of respondents by their professional activity, by including the following groups in the experiment:

1. Teachers: specialists in physics, biology, law, political science and others who were not involved in the experiment.
2. Non-teachers: other professions that are not related to education and pedagogy.

Such a large and diverse sample of respondents will allow us to obtain a Gaussian curve with a normal (statistical) distribution of the essence of emoji language, fractalizing the effect of the exponential function of artificial language into a quadratic function. This way, we will have a deductive hypothesis of the role, function and impact of emoji language on teachers and non-teachers, which will reveal the pros and cons of digitalization of society both in the educational process and beyond. Moreover, this approach will enable us to examine the linguistic construction of individual "Sprachspiel" (term by Wittgenstein [25]) using natural and artificial languages with an emphasis on the apriori-posteriori nature of emoji in digital communication.

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