AREdu 2024: Where augmented reality meets augmented intelligence

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Abstract

The 7th International Workshop on Augmented Reality in Education (AREdu 2024) brought together researchers and practitioners to explore the convergence of augmented reality and artificial intelligence in educational contexts. This paper presents an overview of the workshop's proceedings, comprising 22 peer-reviewed papers spanning diverse areas. Key themes include immersive learning environments, augmented intelligence in education, learning analytics, innovative educational technologies, and AR/VR applications. The papers collectively demonstrate how the integration of AR and AI technologies can enhance learning experiences, improve educational outcomes, and support the development of critical skills. Despite ongoing challenges in Ukraine, AREdu 2024's format enabled global participation and knowledge sharing. The proceedings provide valuable insights to guide future research and implementation efforts in AR-enhanced education.

Keywords

augmented reality, artificial intelligence, educational technology, immersive learning, learning analytics, STEM education, teacher training, educational data mining

1. Introduction

Augmented **R**eality in **Edu**cation (AREdu) is a peer-reviewed international Computer Science workshop focusing on research advances and applications of virtual, augmented and mixed reality in education.



Figure 1: AREdu 2024 logo.

The 2024 edition of the workshop marks a significant evolution in the field, particularly highlighting the convergence of augmented reality with artificial intelligence technologies. This intersection presents

AREdu 2024: 7th International Workshop on Augmented Reality in Education, May 14, 2024, Kryvyi Rih, Ukraine
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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

CEUR-WS.org/Vol-3918/paper000.pdf

new opportunities for creating more adaptive, intelligent, and personalized learning experiences. The workshop's focus on both AR and AI reflects the growing recognition that these technologies, when combined, can provide powerful tools for addressing contemporary educational challenges and supporting innovative pedagogical approaches.

The 7th International Workshop on Augmented Reality in Education (AREdu 2024), held on May 14, 2024, in Kryvyi Rih, Ukraine, provided a dynamic platform for researchers, educators, and technology developers to share their latest findings and experiences in the rapidly evolving field of AR and AI in education. Building on the success of previous editions [1, 2, 3, 4, 5, 6, 7], AREdu 2024 attracted a diverse array of contributions exploring the design, implementation, and evaluation of AR/AI-based learning environments across various educational levels and subject areas.

This year's workshop covers a wide range of topics related to the application of augmented reality and artificial intelligence in various educational contexts:

- Immersive learning environments and tools
- Augmented intelligence in education
- Learning analytics and educational data mining
- Innovative educational technologies and approaches
- AR/VR applications and case studies
- Best practices and lessons learned

This volume represents the proceedings of the AREdu 2024. It comprises 22 contributed papers that were carefully peer-reviewed and selected from 27 submissions. At least three program committee members reviewed each submission.

The workshop's proceedings showcase the breadth and depth of current research on educational AR. From theoretical frameworks to empirical studies and practical applications, the papers collectively demonstrate AR's immense potential to enhance learning experiences, foster engagement and motivation, and develop critical 21st-century skills.

2. AREdu 2024 committees

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3. Proceedings overview

3.1. Immersive learning environments and tools

The paper "Immersive learning tools for teaching mathematics to high school students in general secondary education institutions" by Lytvynova and Rashevska [48] explores the potential of immersive technologies in developing mathematical and information-communication competencies among high school students in specialized classes of general secondary education institutions in Ukraine. The authors provide a literature review, highlighting the growing importance of immersive technologies in education, particularly in the context of the COVID-19 pandemic and the need for innovative teaching approaches. The study focuses on four main immersive learning platforms: AR Book, mozaBook, GeoGebra 3D, and Desmos. For each platform, the authors offer a detailed description of its features, benefits for teachers and students, and specific applications in teaching mathematics to high school students. The paper provides insights into how these platforms can be used to create interactive and engaging learning experiences, personalize learning trajectories, and foster the development of critical thinking and problem-solving skills. The authors conclude by emphasizing the need for further research on the systematic integration of immersive technologies into the Ukrainian education system, the development of adaptive curricula, and the training of teachers to effectively implement immersive learning in their classrooms.

In the paper "Bridging minds and machines: AI's role in enhancing mental health and productivity amidst Ukraine's challenges", Bondar, Bilozir, Shestopalova, and Hamaniuk [49] explore the convergence

of human intelligence and artificial intelligence, focusing on its potential to enhance education in the domain of mental health, particularly within Ukrainian educational institutions following the pandemic and amid wartime conditions. The authors delve into the concepts of "digital mental health", "e-mental health", "mental health technology", and "digital mental health", highlighting their significance in the current context. The paper examines the standards for university courses in mental health technologies and introduces a variety of mental health apps, including wearables, platforms, data analytics resources, and other tools. The authors emphasize the importance of integrating artificial intelligence into both the education and economic sectors, providing a detailed account of an experiment integrated into a standard university curriculum involving master's psychology students at a pedagogical university. The results and conclusions of this experiment are thoroughly presented, offering valuable insights into the practical application of AI in mental health education. Furthermore, the paper investigates the impact of transactional distance on the learning experience of students pursuing mental health technology courses online at Kryvyi Rih State Pedagogical University during the 2023-2024 academic year. The study's findings affirm the critical role of synergizing human and artificial intelligence in addressing pressing challenges, enhancing mental health education, honing data analysis skills, and shaping a brighter future for well-being.

A key strength of the paper "Harnessing immersive technologies for enhancing Japanese language acquisition: Methodological insights for prospective language educator" by Gayevska [50] is its thorough classification and analysis of immersive technologies, clearly delineating the differences between various VR and AR approaches. The authors' systematic breakdown of VR into five categories and AR into three types provides a clear framework for understanding these technologies' educational applications. The visual representations through figures effectively communicate these complex technological relationships.

The empirical research component is notably robust, employing both quantitative and qualitative methods to assess student attitudes and learning outcomes. The survey results from 31 students provide valuable insights into learners' perceptions of immersive technologies, while the comparative analysis of exam results (95 points vs 85 points average) offers concrete evidence of the technology's educational impact.

The paper makes a unique contribution by focusing specifically on the challenges of teaching character-based writing systems. The discussion of using AR for learning Kanji characters is particularly insightful, offering practical solutions for one of the most challenging aspects of Japanese language acquisition. The detailed analysis of student preferences for different learning approaches, including the high rating (5.0) for creating AR-based educational materials, provides valuable guidance for curriculum development.

In the paper "Harnessing immersive technologies for enhancing mathematical logics education in secondary schools", Velychko, Fedorenko, Kaidan, and Kaidan [51] examine the current state and practical applications of immersive technologies in enhancing mathematical logics education in secondary schools. The authors emphasize the importance of visual presentation and quality of new knowledge in the learning process, particularly in light of the rapid development of information and communication technologies. The study explores the possibilities and specifics of employing virtual worlds in the educational process and provides practical results of approbating virtual tools in the classroom.

The paper begins with a literature review, highlighting the growing significance of immersive technologies in education and the potential of edutainment, or learning through play, in engaging students and improving learning outcomes. The authors discuss various types of immersive technologies, including Real Reality (RR), Augmented Reality (AR), Virtual Reality (VR), Mixed Reality (MR), and 360-degree photos and videos, and their applications in educational settings.

A key contribution of this study is the analysis of existing virtual learning environments, such as Lifeliqe's Digital Science Curriculum, Minecraft: Education Edition, and Tinkercad, and their potential for teaching mathematical logics. The authors provide practical examples of how these platforms can be used to create interactive and engaging learning experiences, fostering a deeper understanding of abstract concepts and logical reasoning.

The research methodology includes a survey conducted among students at the Donbas State Ped-

agogical University, studying secondary education in mathematics, physics, and informatics. The survey results reveal that most students are familiar with the concept of gamification, are ready to learn through play, and support the integration of computer games in the teaching process. However, the study also highlights the limited exposure of students to learning through computer games and the need for incorporating gamification elements in teacher training programs.

The paper presents a case study of introducing gamification elements in teaching the topic "Logical Operators" using Minecraft EDU and Tinkercad environments. The results demonstrate a significant increase in student interest and improved learning outcomes, indicating the effectiveness of immersive technologies in teaching mathematical logics.

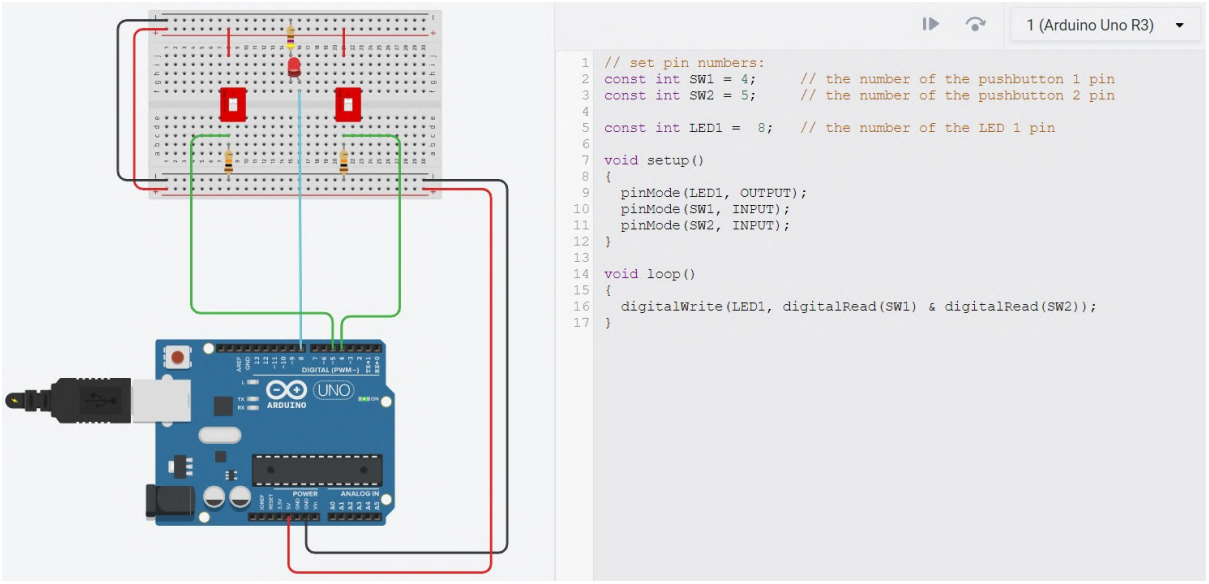


Figure 2: An example of creating a scheme for the logical operator "AND" in Tinkercad [51].

In conclusion, the authors emphasize the potential of gamification in enhancing the quality of education for learners of all ages, deepening the level of acquired knowledge, and enabling more effective use of skills and abilities. However, they also acknowledge the need for establishing clear procedures and adherence to key stages in creating game mechanisms for successful implementation in the education system.

3.2. Augmented intelligence in education

In the paper "A novel pedagogical approach to equipping prospective IT professionals with skills in 3D modelling and reconstruction of architectural heritage", Hevko, Potapchuk, Lutsyk, Yavorska, Hiltay, and Stoliar [52] present a novel pedagogical methodology for teaching prospective IT professionals cutting-edge 3D technologies for the graphical reconstruction of architectural heritage. The effectiveness of the proposed approach is demonstrated through a case study involving the reconstruction of the Parochial Cathedral of St Mary of Perpetual Assistance from the 1950s. The methodology encompasses a comprehensive set of stages: analysis, modeling, design, and 3D printing, underpinned by a synthesis of archival data analysis, parallax estimation from stereo image pairs, and contemporary 3D modeling techniques. The authors detail the selection of 3DS Max as the optimal software for creating the detailed 3D model and Cura for preparing the model for 3D printing. The experimental evaluation confirms the efficacy of the proposed teaching methodology in equipping students with a robust theoretical and practical foundation for deploying modern digital technologies in the reconstruction and preservation of architectural heritage. The proposed approach has the potential to foster the development of essential skills among prospective IT professionals while contributing to the preservation and dissemination of cultural heritage.



Figure 3: The printed miniature of the Parochial Cathedral of St Mary of Perpetual Assistance [52].

In the paper "A novel neuro-fuzzy approach for evaluating educational programme quality and institutional performance in higher education", Ryabko, Vakaliuk, Zaika, Kukharchuk, Kukharchuk, and Novitska [53] present a novel methodology for evaluating the quality of educational programmes and institutional performance in higher education institutions using advanced artificial intelligence techniques, specifically the Adaptive Neuro-Fuzzy Inference System (ANFIS) and multi-layer neural networks. The study addresses the challenges of subjectivity in self-assessment processes and aims to proactively identify potential issues and deficiencies in educational activities prior to accreditation reviews.

The paper begins with a theoretical background, discussing the complexity of evaluating educational quality and the need for quantitative methods to assess non-numerical characteristics. The authors highlight the importance of student-centredness and academic freedom in the accreditation process and emphasize the potential of involving students in the evaluation of educational programmes and institutional activities.

The proposed approach utilizes student ratings on a four-level assessment scale as input data for the

multi-layer neural network, while the criteria for assessing educational programme quality serve as input variables for the ANFIS model. The underlying hypothesis is that students with higher academic performance would provide more objective assessments of the quality criteria.

The authors provide a detailed description of the ANFIS network architecture and the process of training and testing the neural networks using the MATLAB environment. The results demonstrate that the multi-layer neural network exhibits superior predictive accuracy compared to the ANFIS model, with an average absolute error of 0.0321 and a relative error of 7.08% when compared to expert estimates. The authors also highlight the potential of using student and graduate assessments to prepare training datasets for configuring and training artificial neural networks capable of performing comprehensive evaluations of educational programmes and institutional activities.

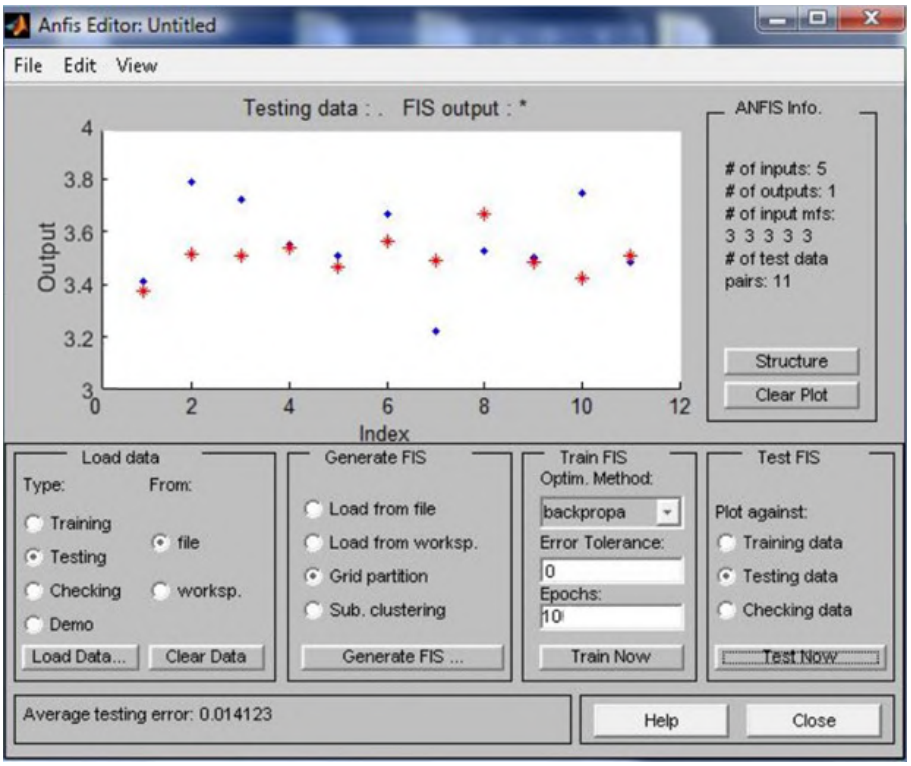


Figure 4: The results of network testing on known values of expert estimates [53].

The discussion section critically evaluates the study's findings, acknowledging the debatable nature of using students as experts in the evaluation process and emphasizing the need for further research with larger datasets to refine the neural network architecture and improve its predictive capabilities. The authors also suggest involving teachers from other educational institutions and increasing the volume of the input vector to include estimates from teachers, stakeholders, and experts.

The paper concludes by underlining the practical implications of the proposed methodology, which can enable higher education institutions to detect shortcomings and potential problems before accreditation examinations. The authors also identify prospects for further research, such as applying neural network-based software products to automate various aspects of the educational process and introducing neural network software for direct student training in specific disciplines.

In the paper "Using intelligent agent-managers to build personal learning environments in the e-learning system", Burov, Pasko, Viunenko, Agadzhanova, and Ahadzhanov-Honsales [54] present a novel approach to developing the structure of a multi-agent environment for e-learning systems and propose a computer technology to ensure student activities in e-learning modular systems. The study addresses the low level of adaptation of modern e-learning systems to individual student characteristics and the lack of ability to predict learning outcomes.

The introduction highlights the importance of delivering dynamic learning materials and managing

training course systems promptly in modern e-learning systems. The authors emphasize the role of intelligent agent-managers in referring students to relevant communities, examining materials accessed by other community members, and connecting students and experts. The main disadvantage of current learning management systems is identified as the failure to provide students with assistance in the distance learning process, necessitating the integration of metacognitive agents for each student.

The paper proposes a three-level multi-agent management architecture for distance learning in e-learning systems, which includes Tutor Agents, Lesson Planning Agents, Learner Agents, and Personalization Agents. The authors focus on learning agents, also known as autonomous intelligent agents, and present the flow of work of an agent-manager as part of the Learning Management System

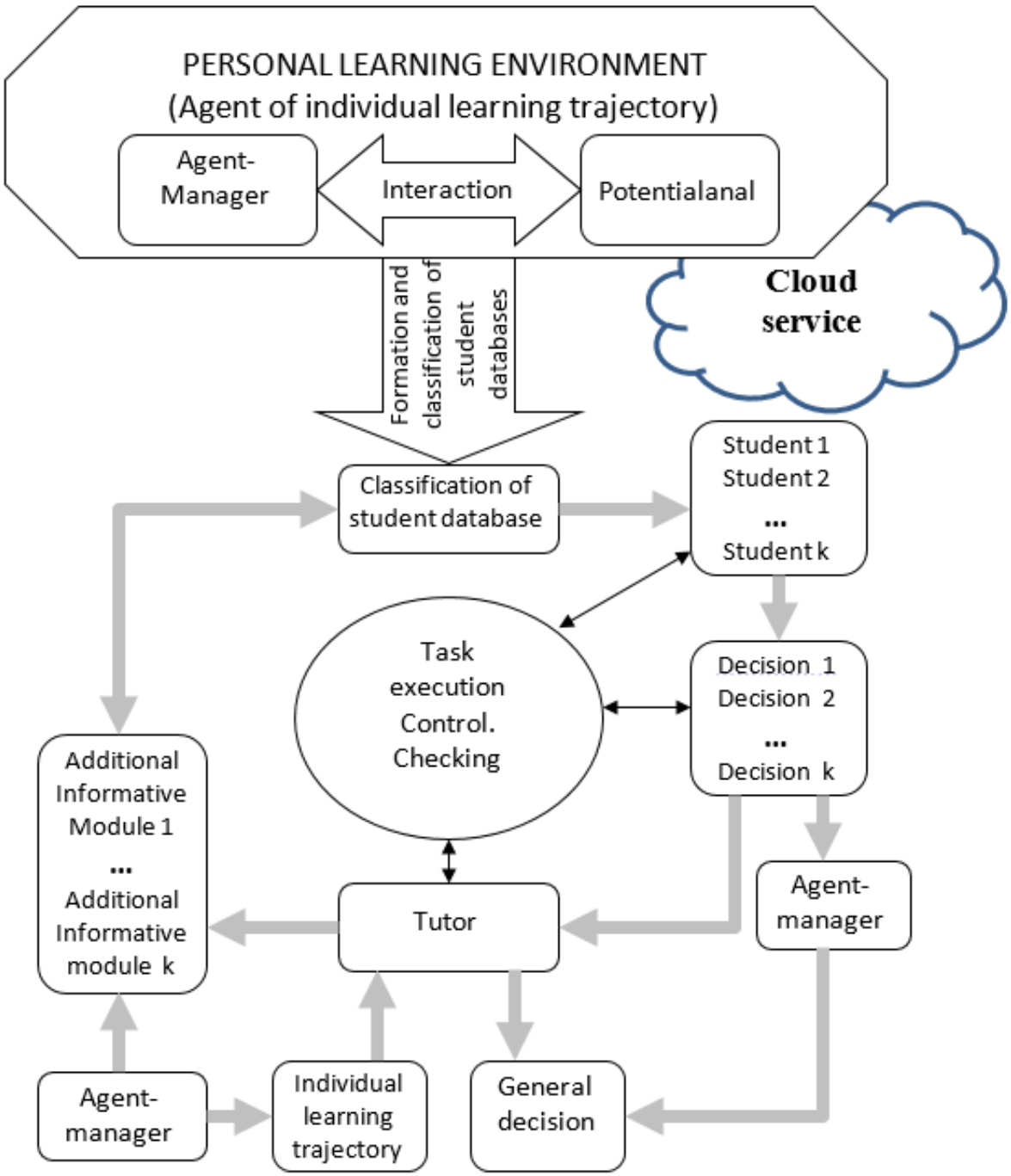


Figure 5: Flow of work of an agent-manager as part of LMS [54].

(LMS). The formalized description of modular e-learning systems to ensure the ergonomic quality of human-machine interaction is addressed through a complex of component and morphological models.

The developed models define the concept of forming the knowledge and data bases of the learning management system in the "agent – manager for e-learning" software package. The basic functional blocks and principle of operation of the agent-manager for e-learning are illustrated, highlighting the interaction between the student model, knowledge model, teaching model, and student-teacher interaction model.

Experiments conducted at Sumy National Agrarian University demonstrate the effectiveness of the developed models and computer technology. The quality expertise and evaluation of the parameters of electronic training modules "Informatics" for first-year students of the "Agronomy" specialty were carried out.

The proposed technology enables the consideration of factors affecting students' learning outcomes from a holistic perspective and the formation of an individual trajectory for each learning session. The authors conclude by emphasizing the potential of their approach to provide users with the opportunity to collect, analyze, distribute, and use knowledge in the e-learning system from various independent sources.

In the paper "AI tools for sustainable primary teacher education: literary-artistic content generation", Nezhyva, Palamar, Semenii, and Semerikov [55] explore the possibilities of using AI tools for generating literary-artistic content in preparing primary school teachers for professional activities. The study aims to determine the familiarity and readiness of future primary school teachers to use AI in the literary field, reveal the possibilities of applying AI to prepare teachers for organizing the study of literary works, describe AI tools that can motivate young students to read, and highlight the advantages and disadvantages of using AI programs to generate literary-musical and video content based on literary material.

The introduction provides an overview of the growing interest in AI applications in education and the potential of AI tools in transforming teaching and learning methods. The authors emphasize the importance of preparing future primary school teachers to effectively integrate AI technologies into their professional activities, particularly in the context of literary education.

The study's methodology employs a mixed-methods approach, combining surveys, hands-on experiences with AI tools, and the analysis of student-generated artifacts. The participants, 138 bachelor's students specializing in "Primary Education" at Borys Grinchenko Kyiv Metropolitan University, were introduced to various AI tools for generating literary-musical and video content, such as Suno, Udio, Boomy, Pictory, Lumen5, and InVideo AI. Data were collected through surveys, pedagogical cases, multimedia didactic tools, and observations.

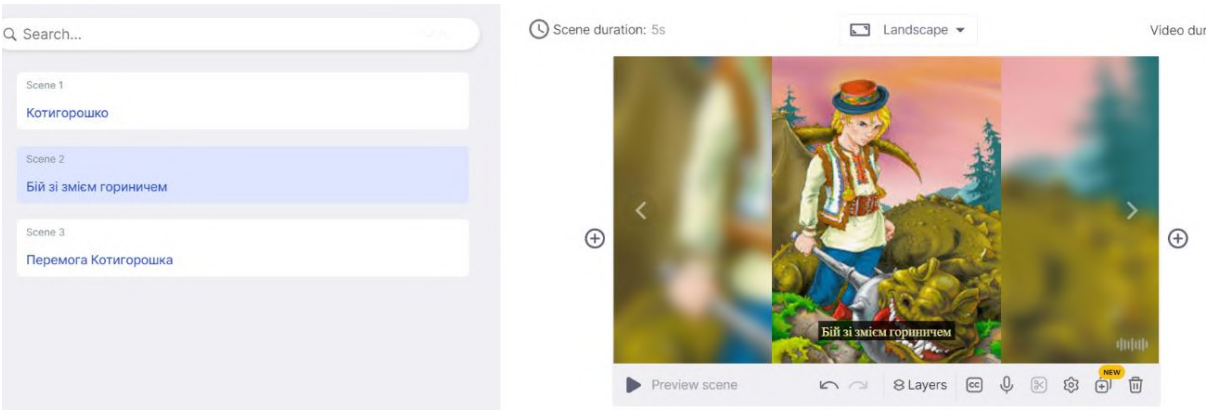


Figure 6: An example of the generation of the tale "Kotygoroshko" in the Pictory program [55].

The results section provides a detailed analysis of the AI tools tested by the students, highlighting their features, advantages, and disadvantages for creating literary-musical and video content. The authors present practical examples of how these tools can be used to enhance the study of literary

works in primary education, such as creating songs based on poems, generating dialogues between characters, and visualizing writers' biographies.

The discussion section underscores the potential of AI tools in creating engaging and interactive literary-artistic content, facilitating personalized learning, and supporting the development of students' creativity and critical thinking skills. The authors also address the challenges and limitations identified during the study, such as the need for content validation, technical support, and addressing ethical concerns.

The study proposes measures to ensure the responsible and beneficial implementation of AI in primary education, including rigorous content validation processes, teacher training, and the development of clear policies for transparent and ethical AI usage. The authors emphasize the importance of integrating AI technologies into teacher education programs to foster digital literacy skills, promote innovative teaching methods, and cultivate a mindset of continuous learning and adaptation.

The conclusion highlights the significance of the study's findings in contributing to sustainable education practices by preparing future primary school teachers to effectively harness the potential of AI technologies while navigating the challenges and opportunities presented by the digital age. The authors call for further research to explore the long-term impact of AI integration on student learning outcomes, develop comprehensive AI competency frameworks, and refine ethical guidelines for AI use in educational settings.

In the paper "A model for improving the accuracy of educational content created by generative AI", Talaver and Vakaliuk [56] present a novel approach for text processing and factual claims verification to address the critical challenge of ensuring the reliability of AI-generated educational content. The study focuses on extracting factual claims, retrieving evidence from authoritative sources, verifying content, and rewriting it to ensure accuracy while maintaining pedagogical effectiveness.

The introduction provides an overview of the transformative impact of AI in education, highlighting the potential of large language models (LLMs) in enhancing the accessibility, quality, and relevance of learning materials. The authors emphasize the need for a system that complements manual peer review processes by providing detailed annotations and evidence-based notes related to facts retrieved from different sources.

The theoretical background section offers a thorough review of the growing influence of AI in education, the SME-driven approach to content creation, and the challenges and limitations of generative AI for learning. The authors discuss the risks of bias, inaccuracies, and ethical concerns, underscoring the importance of robust, multi-layered validation frameworks. They also highlight the utility of the Swiss Cheese Model and the need for adaptable guardrail solutions to mitigate these challenges.

The methods section outlines the development of the proposed system, which employs a multi-layered approach to content verification. The workflow incorporates multi-stage processing, structured claim extraction, evidence classification, and revision strategies, with a focus on prompt engineering techniques and adherence to factual accuracy. The testing methodology, which includes articles with altered factual information, demonstrates the system's ability to detect inaccuracies.

The results section presents a simple web UI that supports the visualization of the verification process. The processed text contains highlighted parts representing analyzed claims, with color-coding indicating the certainty of the decision and the presence of revisions. The popup functionality provides detailed information about each claim, including the revised paragraph, an explanation of the changes, certainty scores, and aggregated evidence counts.

The discussion section highlights the strengths of the proposed method, including its clear and practical framework, the use of prompt-chaining techniques, and its cost efficiency. The authors also acknowledge the challenges faced by the system, such as occasionally missing specific claims or failing to provide adequate context. They suggest fine-tuning the model with more varied and representative training examples to enhance its contextual understanding and precision.

The conclusion emphasizes the potential of the proposed approach in addressing text verification and content refinement challenges. The authors encourage researchers and developers to explore and refine the system in real-world settings to ensure its full potential is realized across domains.

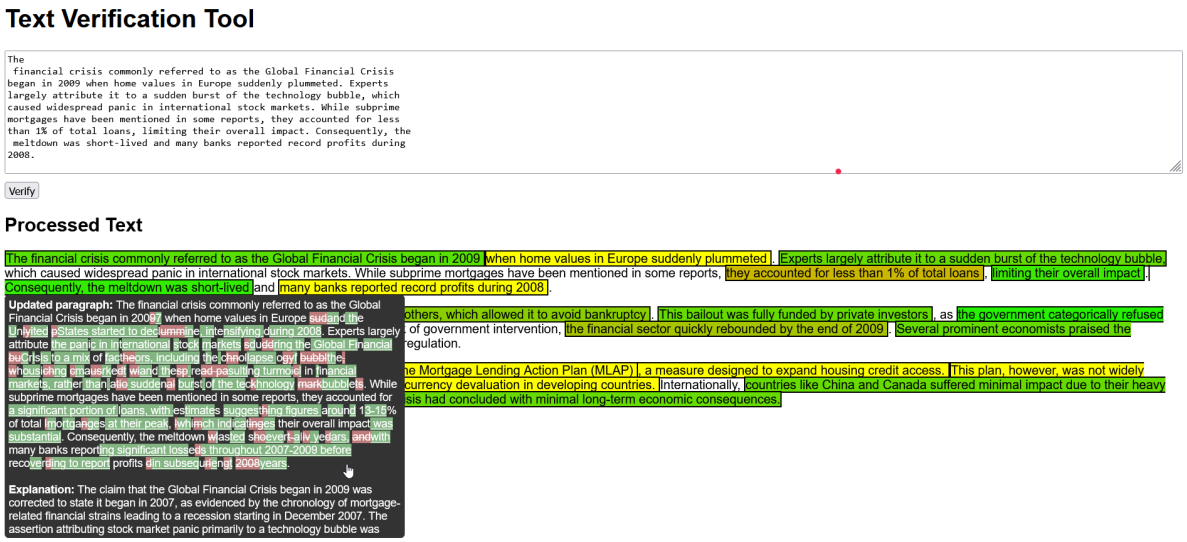


Figure 7: An example of the verification tool UI includes a field with inserted text and processed output that provides suggestions for different parts and a popup with details that are opened upon hovering highlighted parts of the text [56].

3.3. Learning analytics and educational data mining

In the paper "The role of educational and scientific studies taxonomies in a centralised informational web-oriented educational environment", Shapovalov, Shapovalov, Tarasenko, Usenko, Paschke, and Shapovalova [57] explore the use of educational and scientific studies taxonomies in a centralized informational web-oriented educational environment. The authors propose structuring scientific and educational studies using the formalization of the IMRAD approach to provide data interoperability. The study focuses on using study results as part of a centralized informational web-oriented educational environment and applies this structurization to two specific studies related to the utilization of methane tank waste and effluent. The authors describe the use of specific tools from CIT Polyhedron to process

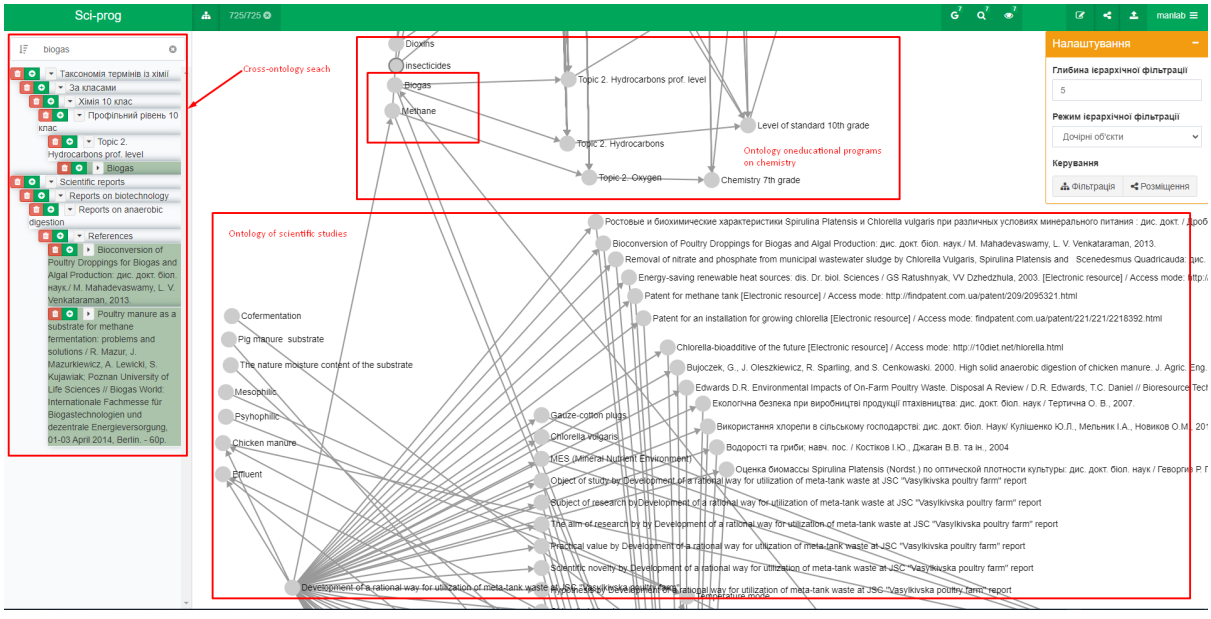


Figure 8: Using of same terms to provide interoperability between educational programmes ontology and scientific studies ontologies [57].

study data, including an audit tool that compares newly inputted data to existing taxonomies and highlights cases of full correspondence between elements of different works. The paper also presents the approach of integrating studies with educational ontologies within the centralized informational web-oriented educational environment, along with a mathematical formalization of this process.

In the paper "Digital modeling of the ecophilic tendencies of university students' consciousness", Klochko, Fedorets, Sharyhin, and Kaplinskyi [58] present a digital modeling approach to study the ecophilic tendencies of university students' consciousness, based on the integrative application of digital, mathematical, anthropological, and psychological methods. The study aims to contribute to the understanding of the psychological, value, cognitive, and behavioral factors in the development of environmental consciousness and human behavior, which are crucial for achieving the Sustainable Development Goals.

The introduction provides a comprehensive overview of the importance of developing ecologically oriented human qualities as a prerequisite for ecologically oriented behavior. The authors emphasize the role of ecophilic tendencies of consciousness as a psychological prerequisite for the formation of these qualities, justifying the need for their digital and mathematical modeling.

The methodology section describes the application of various methods, including system analysis, cluster analysis, mathematical statistics, digital modeling, and digital data visualization. The authors employ the Hubert index, hierarchical clustering with Ward's minimum variance method, and distance matrix to determine the optimal number of clusters. They also use the K-Means and Canopy clustering methods to structure the objects into clusters.

The results section presents the findings of the study, revealing that the optimal number of clusters is 3, but the authors decide to divide the set of objects into 4 clusters to capture the unique structure of the cluster for diagnosing the ecophilic intentions and values of university students. The cluster models obtained using the K-Means and Canopy methods are similar, confirming the effectiveness of the algorithms and the adequacy of the constructed cluster structures.

The discussion section compares the study's findings with the work of other researchers, highlighting the conceptual proximity and the potential of the existential and harmonizing aspect of greening as a strategy for shaping consumer environmental behavior and fostering creativity, innovation, altruism, and compassion.

The conclusion emphasizes the importance of the study's results in developing strategies for the ecologization of higher education students. The authors conceptualize two directions of ecologization: existentially harmonizing and aesthetically harmonizing. These directions are used to develop ecophilic tendencies of consciousness in future mathematics teachers, students of information technology, and to improve the health-saving competence of physical education teachers.

3.4. Innovative educational technologies and approaches

In the paper "Enhancing personal financial management skills through a machine learning-powered business simulator", Antoniuk, Vakaliuk, Didkivskyi, Vizghalov, Oliinyk, and Yanchuk [59] introduce a novel web-based business simulator equipped with machine learning capabilities to facilitate the development of personal financial management skills. The paper begins by highlighting the importance of effective personal financial management as a critical life skill and the lack of sufficient financial literacy among university students in Ukraine. The authors present a comprehensive methodology for utilizing the simulator, including its content, objectives, formats, methods, and tools. The key features and sections of the simulator are described in detail, along with the specific personal finance management skills it aims to cultivate. To enhance the simulator's effectiveness, elements of machine learning, particularly reinforcement learning, have been incorporated. The authors emphasize the simulator's versatility, as it is designed to cater to a wide audience, from school-aged children to adults, and can be integrated into economics courses at both secondary and tertiary education levels in Ukraine. The paper concludes with a discussion on the future prospects of using such simulators to develop managerial and financial competencies among students from diverse specialties.

The paper "Collaborative learning in the system of training future information technologies specialists

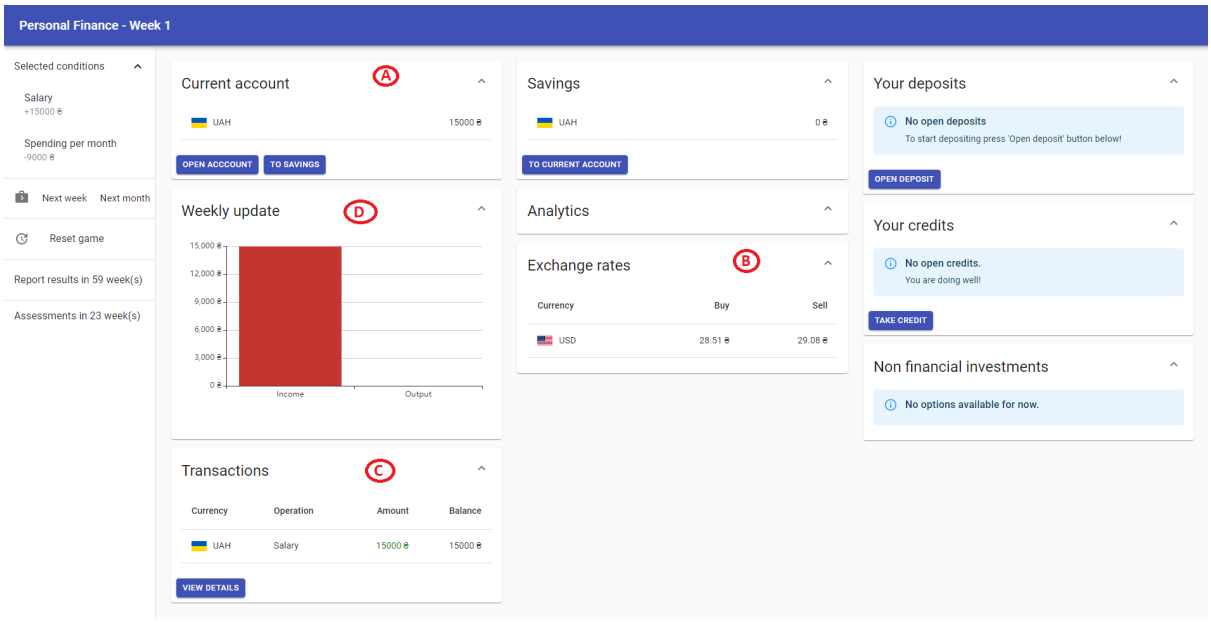


Figure 9: Business simulator [59].

as an educational strategy for the fundamentalization of the sustainable development of education" delves into the role of collaborative learning in the training of future information technology (IT) specialists. Authored by Tverdokhlib, Klochko, Sharyhin, and Fedorets [60], the study explores how collaborative learning can be integrated into IT education to enhance teamwork skills, problem-solving abilities, and contribute to the sustainable development of education. The research is grounded in both empirical and theoretical frameworks, with a particular focus on the distinction between cooperative and collaborative learning, and proposes a methodology for using collaborative learning in the context of team sports programming.

The paper provides a clear distinction between cooperative and collaborative learning. Cooperative learning involves the division of tasks among group members, whereas collaborative learning emphasizes a more integrated, psychologized, and intellectualized approach, where group members work together to solve problems and achieve common goals. This distinction is crucial for understanding the synergistic effects of group work in educational settings.

The authors propose a structured methodology for implementing collaborative learning in IT education, particularly in the context of team sports programming. The methodology includes iterative processes such as team formation, role definition, training, and evaluation. Specific collaborative techniques like pair programming, joint code development, code review, retrospectives, and code sessions are recommended to enhance teamwork and problem-solving skills.



(a) (b)

Figure 10: Word cloud of keywords characterizing the concept of cooperative learning (a) and collaborative learning (b) [60].

The study includes a survey of university lecturers involved in IT education. The survey results, analyzed using system analysis, Natural Language Processing (NLP), and statistical methods, reveal that while cooperative learning is more commonly used, collaborative learning has a significant positive impact on students' teamwork skills, problem-solving abilities, and emotional and cognitive interactions within groups.

The paper aligns collaborative learning with the broader goals of sustainable development in education, particularly SDG 4, which aims to ensure inclusive and equitable quality education. By fostering teamwork, critical thinking, and problem-solving skills, collaborative learning prepares students to address global challenges and contribute to a sustainable future.

The findings suggest that collaborative learning can be particularly effective in preparing students for team-based activities such as sports programming. The iterative process of team formation and role definition, combined with collaborative techniques, can lead to better performance and a deeper understanding of complex tasks.

The paper "Harnessing online services for creating augmented reality enhanced comics in primary education" by Bodnenko, Lokaziuk, Poryadchenko, and Proshkin [61] explores the use of cloud services to create augmented reality (AR)-enhanced comics in primary education. It highlights the didactic potential of comics as an educational tool and provides a comparative analysis of modern cloud services, programs, and applications for comic creation. The study also examines the functionality of AR programs like Vuforia, EasyAR, and ARCore. Through a survey of teachers, the most popular cloud services (Pixton, Marvel HD, Comica) are identified, and algorithms for developing AR-enhanced comics are presented. The paper concludes with the development of educational and methodological support for teachers and students, aiming to improve their readiness to use these technologies in primary education.

The paper "Methodological foundations of teaching the basics of artificial intelligence to lyceum students" by Tarasova and Doroshko [62] makes a significant contribution to the field of AI education by developing and validating a comprehensive methodological framework for teaching artificial intelligence concepts to lyceum (upper secondary) students in Ukraine. The research addresses a critical gap in current educational practices as countries worldwide grapple with how to effectively integrate AI education into secondary school curricula.

The authors present a well-structured multi-phase research approach that combines theoretical analysis with practical implementation. Their review of existing textbooks and educational materials reveals important gaps in current AI coverage, finding that only 3.5% of content in Ukrainian informatics textbooks addresses AI-related topics. This quantitative analysis is particularly valuable as it provides concrete evidence of the need for more comprehensive AI education resources.

A key strength of the paper is its development and evaluation of an innovative three-part web quest complex. This educational tool demonstrates how theoretical concepts can be effectively translated into engaging, interactive learning experiences. The pilot study with 20 lyceum students yielded promising results, with 85% reporting increased engagement and 90% showing improved understanding of AI concepts. These findings provide important validation of the proposed teaching methodology.

The methodological framework presented is notably comprehensive, addressing four crucial components: core AI concepts and skills, teaching approaches, curriculum design guidelines, and teacher professional development recommendations. This holistic approach recognizes that successful AI education requires not just well-designed content, but also appropriate pedagogical strategies and teacher support systems.

The paper's emphasis on incorporating real-world applications and ethical considerations into AI education is particularly timely and relevant. This approach helps prepare students not just technically, but also to think critically about the societal implications of AI technologies.

The paper "The use of ICT by teachers for the development of students' critical thinking in the context of sustainable development in Ukraine" by Ovcharuk, Marienko, Hrytsenchyk, Kravchyna, and Malytska [63] provides crucial insights into how Ukrainian educators are adapting to wartime conditions through the use of ICT to develop students' critical thinking skills. The research is particularly valuable as it documents the challenges and innovations in education during an unprecedented period of disruption, with implications for understanding educational resilience in crisis situations.



Figure 11: Example of a comic created using the Pixton online service [61].

The authors present compelling data on the current state of Ukrainian education, noting that only about one-third of schools operate fully in-person, while the remainder must rely on remote or blended learning approaches. Their nationwide survey of teachers' ICT usage reveals important patterns in tool adoption, with Viber (78.4%), Zoom (65.4%), and Google Apps for Education (53.1%) emerging as the most widely used platforms. The significant increase in Google Apps adoption from 20.2% in the previous year suggests rapid digital transformation in response to crisis conditions.

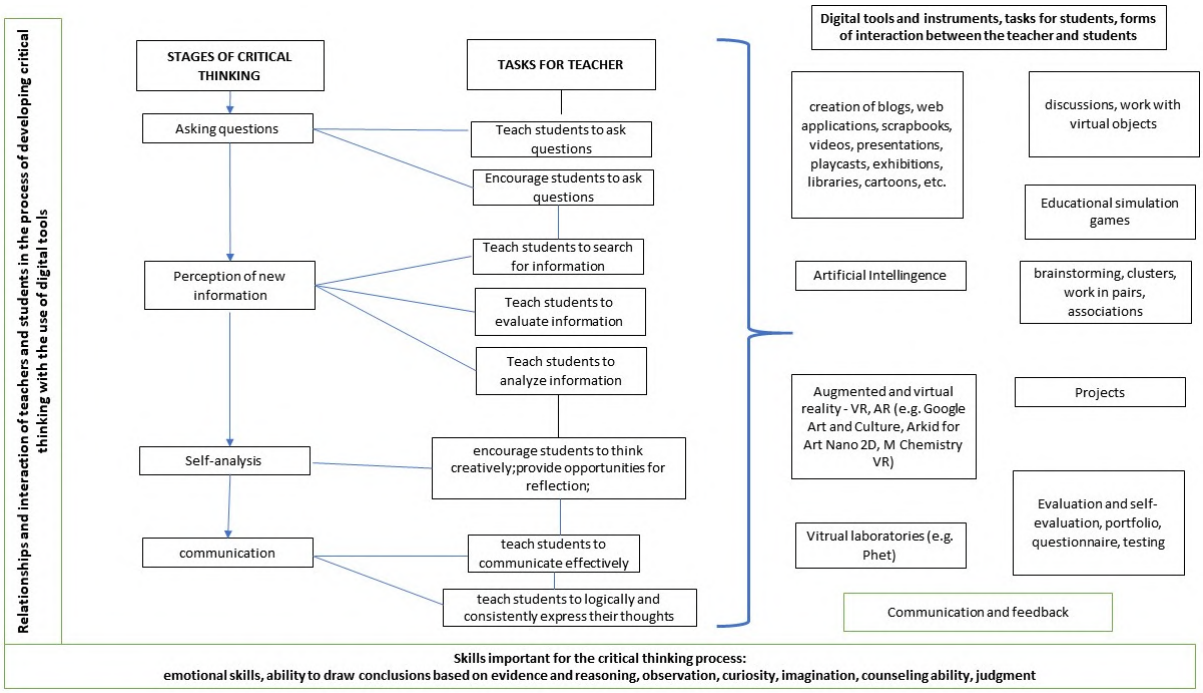


Figure 12: Relationships and interaction of teachers and students in the process of developing critical thinking with the use of digital tools [63].

The research makes a valuable contribution by linking ICT usage to both critical thinking development and sustainable development goals. The authors effectively demonstrate how digital tools can support the twin objectives of maintaining educational continuity during crisis conditions while fostering essential 21st-century skills. Their framework connecting teacher actions, ICT methods, and student outcomes provides a practical model for educators working in challenging circumstances.

A particular strength of the paper is its attention to teacher professional development needs. The finding that 79.2% of teachers rely on administrative emails for information about ICT training, while only 54% receive such information from professional development institutions, highlights important gaps in teacher support systems that need to be addressed.

The authors' recommendations for improving ICT integration and critical thinking instruction are well-grounded in their empirical findings. Their call for more systematic teacher training, parent engagement, and psychological support reflects a holistic understanding of the challenges facing education systems in crisis situations.

While the paper effectively documents current practices and challenges, it could benefit from more detailed discussion of successful pedagogical strategies for developing critical thinking through ICT. Additionally, greater attention to the specific needs of displaced students and teachers would strengthen its practical applications.

The paper "Blended learning: definition, concept and relevance to education for sustainability" by Mintii [64] makes a significant contribution to the field of educational technology by providing a comprehensive analysis of blended learning terminology and conceptualization, with particular attention to its implementation in the Ukrainian educational context. The paper's thorough examination of terminology across multiple European languages and educational systems offers valuable insights for standardizing educational terminology in the context of European integration.

The author's methodology is particularly noteworthy, employing a systematic analysis of both academic literature and practical implementations across different European countries. The detailed comparison of terminology usage, visualized through geographical mapping, provides a clear and convincing argument for the adoption of "kombinovane navchannia" (combined learning) as the most appropriate Ukrainian term for blended learning.



Figure 13: Definition of "blended learning" on the European map: countries that use the word "combining" are marked with a green marker, "mixing" with a red marker, "mixing" and "combining" with a blue marker [64].

A key strength of the paper is its thorough examination of the conceptual foundations of blended learning. The author moves beyond simple definitions to explore the complex interplay between face-to-face and online learning modalities, formal and informal educational approaches, and the role of intelligent technologies in creating adaptive learning environments. The resulting definition of blended learning as a "planned, pedagogically balanced, adaptive combination" represents a sophisticated understanding of the concept that goes beyond mere technological integration.

The paper makes a particularly valuable contribution by linking blended learning to sustainable development goals and European digital education initiatives. This connection demonstrates how blended learning can serve as a strategic tool for achieving broader educational and social objectives, particularly in the context of Ukraine's European integration processes.

The analysis of intelligent technologies' role in blended learning environments is forward-thinking, highlighting how machine learning, learning analytics, and AI-driven systems can enhance personalization and effectiveness. This aspect of the research is especially relevant given the rapid advancement of AI technologies in education.

While the paper's comprehensive literature review and linguistic analysis are impressive, future research could benefit from more empirical evidence about the effectiveness of different blended learning approaches in the Ukrainian context. The author acknowledges this in the proposed future research dimensions, which appropriately encompass philosophical, psychophysiological, sociological, and technological aspects.

The paper "Social media as a tool for career guidance in higher education" by Tkachuk, Yechkalo,

Bielikova, Kolomoiets, Zinchenko, and Semerikov [65] makes a contribution to understanding how social media can be effectively leveraged for career guidance in higher education. The research is particularly valuable for its systematic methodology and evidence-based approach to integrating digital platforms into career counseling practices.

A key strength of the paper is its thorough theoretical framework that builds upon Social Career Cognitive Theory, demonstrating how digital interactions influence career choices and professional identity formation. The authors effectively illustrate this through well-designed figures that map out implementation strategies and theoretical relationships.

The methodology section is notably robust, presenting a clear three-tiered system of engagement, monitoring, and evaluation. The comparative analysis of different social media platforms (LinkedIn, Instagram, Facebook, and Twitter (X)) provides actionative insights for practitioners, with LinkedIn showing superior career outcomes (68%) despite Instagram's higher student adoption rate (89%).

The experimental study is particularly compelling, using a controlled design to test specific pedagogical conditions. The results show meaningful improvements across all measured criteria in the experimental group, with increases ranging from 9% to 18.2%. This empirical validation strengthens the paper's theoretical propositions and provides concrete evidence for the effectiveness of social media-based career guidance when properly implemented.

The authors' visualization of performance trends throughout the academic year effectively demonstrates the progressive impact of their methodology, with student engagement increasing from 65% to 88% and career progress improving from 58% to 82%. These metrics provide valuable benchmarks for other institutions implementing similar programs.

3.5. AR/VR applications and case studies

The paper "Leveraging augmented reality in a mobile application for effective advertising of educational services: an efficiency analysis" by Marchuk, Levkivskyi, Graf, Marchuk, and Panarina [66] makes a contribution to understanding the practical application of augmented reality technology in higher education marketing and recruitment. The research provides both technical implementation details and empirical evidence of AR's effectiveness in engaging prospective students.

A key strength of the paper is its comprehensive documentation of the technical development process using Unity and Vuforia. The authors clearly outline the creation of 3D models, system architecture, and interface design, providing a practical blueprint for other institutions interested in implementing similar solutions. The inclusion of detailed diagrams and screenshots enhances the reproducibility of their approach.

The empirical analysis is particularly noteworthy, examining data from 1,086 applicants across multiple dimensions. The findings reveal significant engagement with the AR application, with 58% of applicants utilizing the technology. The detailed breakdown by specialty provides valuable insights into the varying effectiveness of AR across different programs, with Software Engineering showing particularly strong results (60% of applications).

The statistical analysis is thorough and well-presented, using appropriate descriptive statistics and exploratory analysis techniques. The visualization of results through multiple figures effectively communicates key findings about enrollment patterns, advertising exposure, and competitive scores. The analysis of gender differences in application patterns adds an important dimension to understanding the technology's impact across different demographic groups.

The authors effectively highlight both successes and limitations of their implementation. For instance, they note that while Computer Science had more enrollments than AR views, this was due to geographical limitations in the application's availability rather than a failure of the technology itself. This kind of critical analysis strengthens the paper's credibility.

One minor limitation is that while the paper effectively demonstrates correlation between AR usage and application rates, it could have provided more discussion of causation versus correlation in the relationship between AR exposure and enrollment decisions. Additionally, a more detailed examination of the cost-benefit aspects of implementing such technology would be valuable for institutions

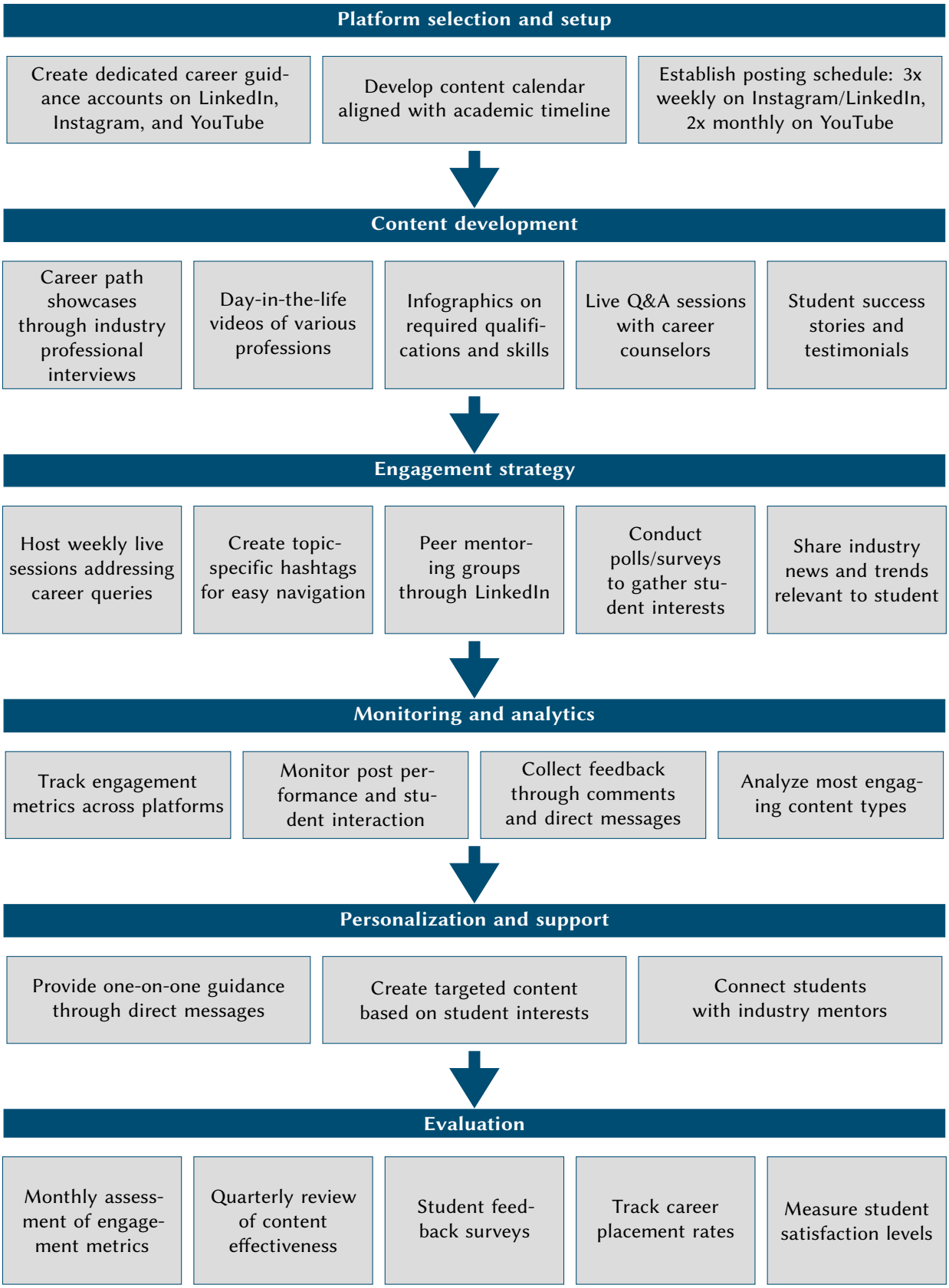


Figure 14: Implementation steps of methodology of using social media [65].

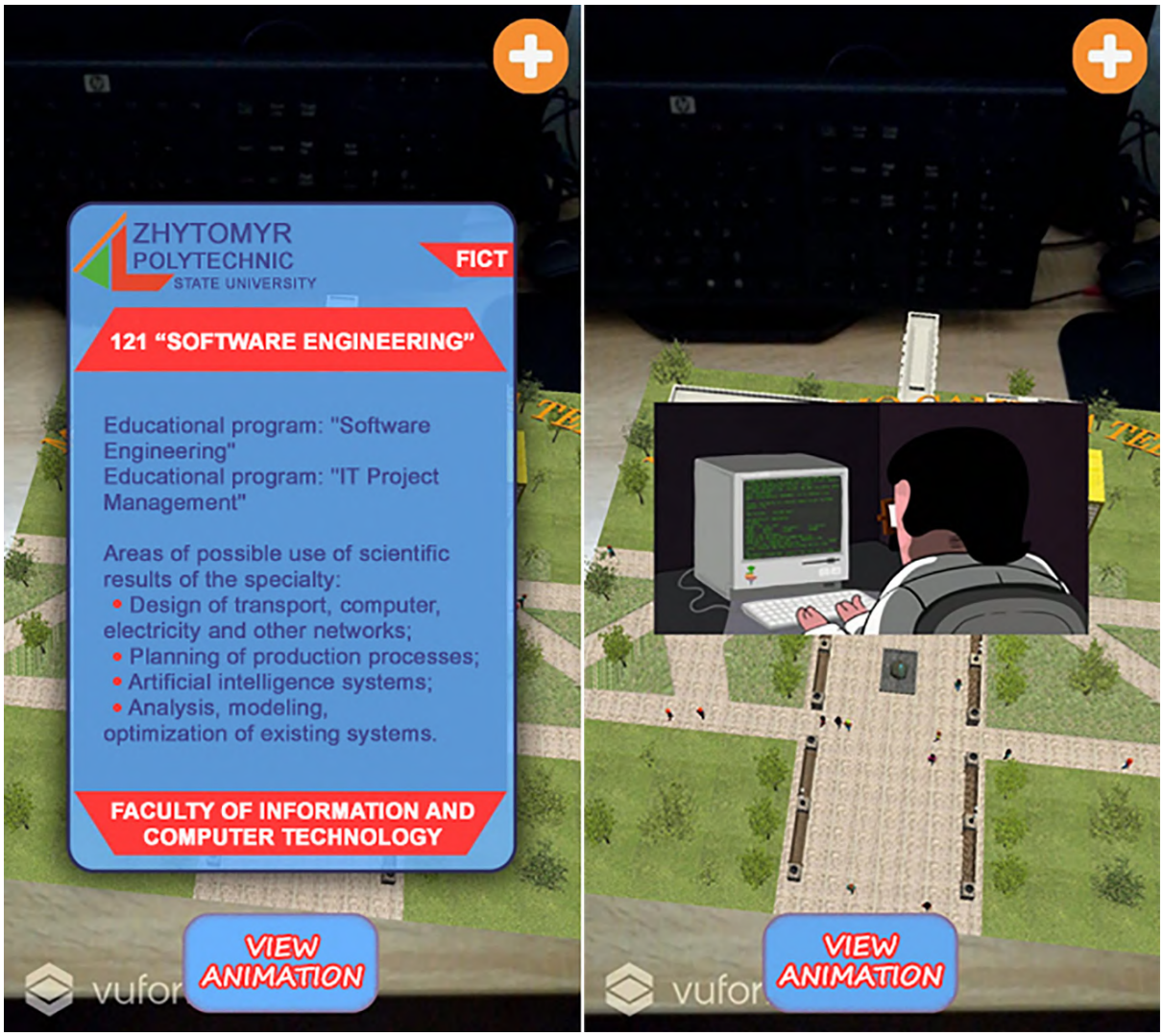


Figure 15: The result of pressing the "I" button in the mobile application [66].

considering similar initiatives.

The paper "Experience in developing and implementing virtual tours using 360° video technology in the educational environment" by Pushkar, Bobarchuk, Denysenko, and Halchenko [67] makes a contribution to understanding both the technical and pedagogical aspects of implementing 360° video technology in higher education. The research is particularly valuable for its practical demonstration of how immersive technologies can enhance educational experiences while remaining more accessible than full VR/AR solutions.

A key strength of the paper is its comprehensive analysis of 360° video technology in comparison to other immersive technologies. The authors effectively demonstrate through clear comparisons how 360° video offers a balanced approach between immersion and accessibility, making it particularly suitable for educational applications. Their detailed comparison table of AR, VR, and 360° video technologies provides valuable insights for institutions considering immersive technology adoption.

The paper's methodology section is exemplary, providing a detailed, step-by-step framework for implementing 360° video projects in educational settings. The five-phase implementation process outlined in figure 16 offers a practical blueprint that other institutions can follow. The authors' attention to technical details, from equipment selection to post-processing requirements, makes this framework particularly valuable for practical implementation.

The discussion of pedagogical applications is thorough and well-reasoned, particularly in the context

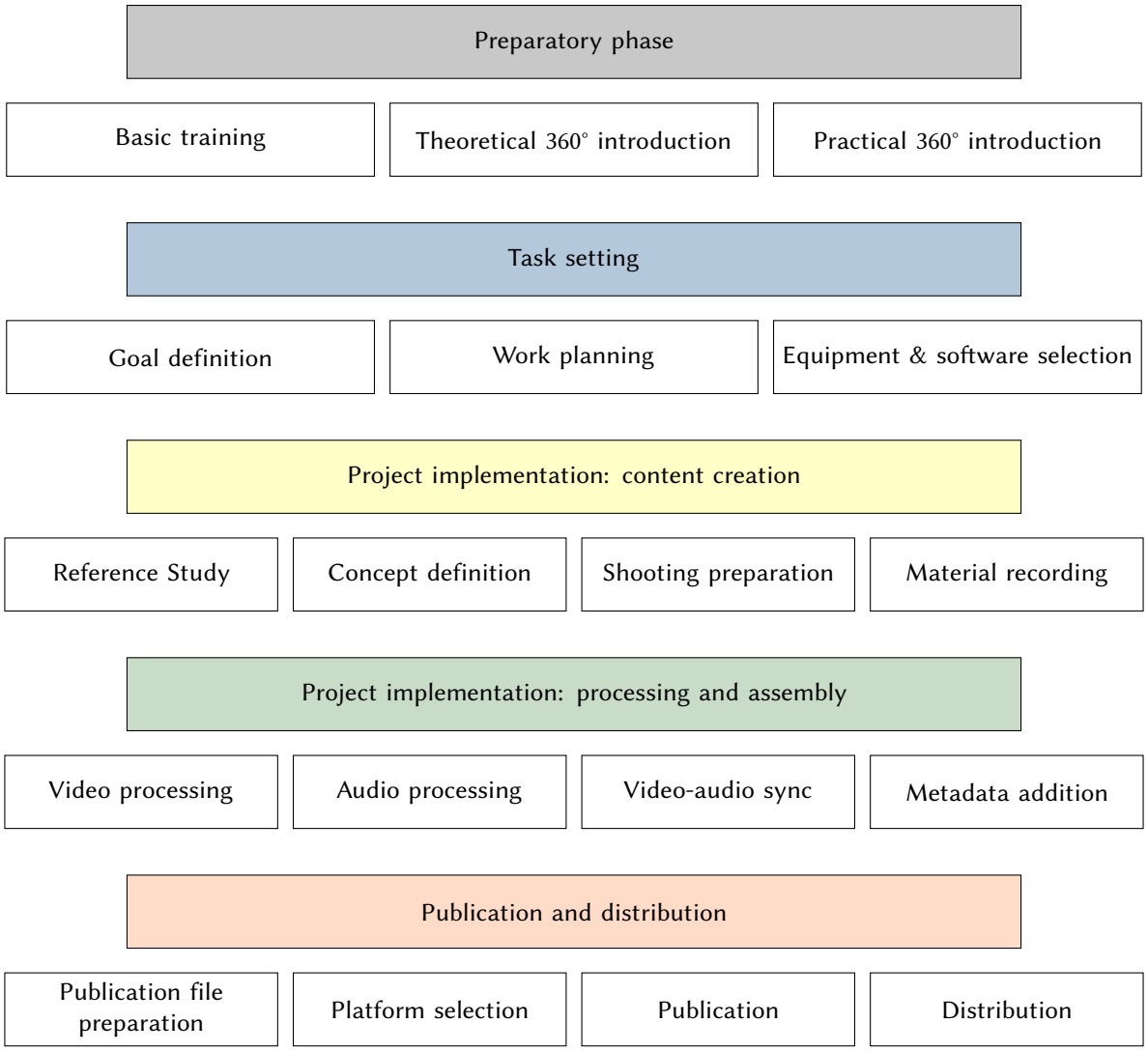


Figure 16: Stages of implementation of an educational project to create a 360° video [67].

of publishing and printing education. The authors identify multiple specific applications, from production process demonstration to risk-free training scenarios, demonstrating a deep understanding of both the technology's capabilities and educational needs.

The case study of creating a university virtual tour provides concrete evidence of the methodology's effectiveness. The detailed documentation of the technical process, including frame sketching, video stitching, and post-processing, offers valuable practical guidance for similar projects. The inclusion of visual examples strengthens the paper's instructional value.

The paper "Theoretical and practical aspects of using artificial intelligence technologies in the field of sound design" by Bobarchuk, Halchenko, Hnidenko, and Zavadetskyi [68] makes a contribution to understanding both the theoretical foundations and practical applications of AI in sound design. The research successfully bridges the gap between technical capabilities and creative implementation, providing insights relevant to both researchers and practitioners.

A key strength of the paper is its comprehensive analysis of the evolution of sound design, from traditional methods to modern AI-driven approaches. The authors effectively demonstrate how AI technologies are transforming the field while acknowledging both their potential and limitations. The clear delineation between classical sound design principles and emerging AI capabilities provides valuable context for understanding this transformation.

The practical implementation section is particularly noteworthy, presenting a concrete case study of

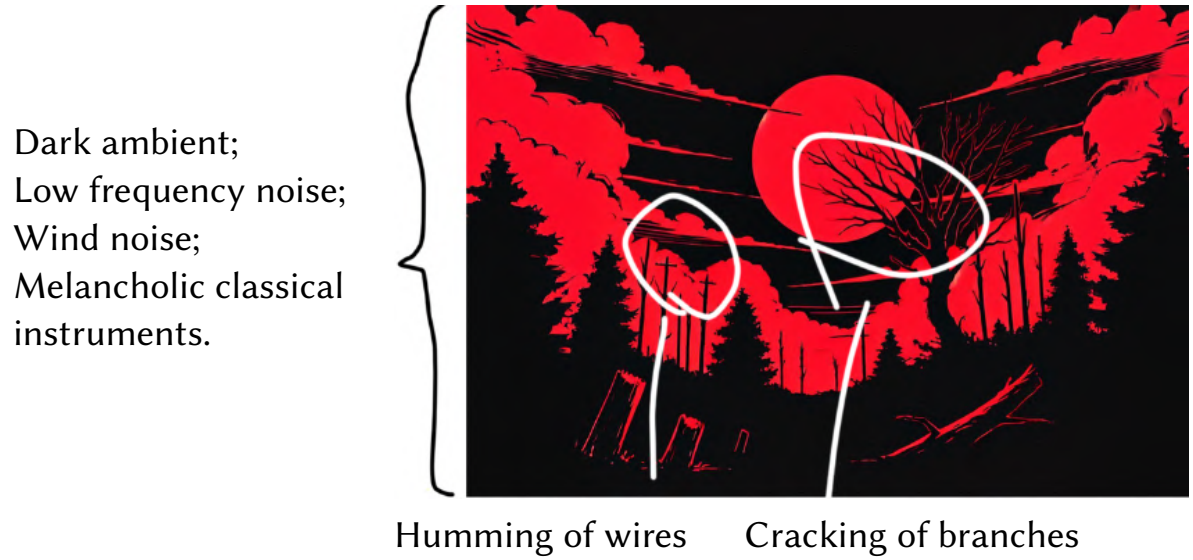


Figure 17: Determining sounds for the scene [68].

creating sound design for visual novels using various AI tools. The step-by-step documentation of using tools like Suno AI, AudioGen, and Synplant2 provides valuable insights into the practical challenges and opportunities of AI-assisted sound design. The authors' candid discussion of both successes and limitations in their implementation adds credibility to their findings.

The paper makes a unique contribution by integrating multiple AI tools in a complementary workflow, demonstrating how different technologies can be combined to overcome individual limitations. Their systematic approach to breaking down scenes into component sounds and matching them with appropriate AI tools provides a useful framework for similar projects.

3.6. Best practices and lessons learned

The paper "Implementing MLOps practices for effective machine learning model deployment: A meta synthesis" by Hanchuk and Semerikov [69] makes a significant contribution to the field of machine learning operations by systematically analyzing and synthesizing findings from multiple systematic reviews on MLOps practices. The paper's methodological approach, following Chrastina's framework, provides a rigorous foundation for integrating insights across the literature.

The paper's key strength lies in its systematic organization and thorough examination of MLOps across multiple dimensions – from theoretical foundations to practical implementation challenges. The authors effectively synthesize findings about MLOps workflows, tools, frameworks, and deployment methods, providing a holistic view of the field that will be valuable to both researchers and practitioners.

Particularly noteworthy is the paper's treatment of MLOps maturity models and assessment frameworks. The authors identify and analyze several approaches to measuring MLOps maturity, from Amershi's adaptation of the Capability Maturity Model to Lwakatare's five-stage development framework. This analysis provides organizations with concrete benchmarks for assessing and improving their MLOps practices.

The clear delineation of roles and responsibilities in ML model operationalization is another valuable contribution. The paper effectively maps out the interactions between data scientists, engineers, domain experts, and management, highlighting the cross-functional nature of successful MLOps implementation.

The authors' analysis of challenges and open issues is particularly insightful, identifying both technical hurdles (like managing model lifecycles and ensuring scalability) and organizational challenges (such as skill gaps and communication issues). The discussion of future trends and opportunities provides valuable direction for both research and industry development.

4. Conclusion

The proceedings of the 7th International Workshop on Augmented Reality in Education (AREdu 2024) showcase the rapid evolution and maturation of AR and AI technologies in educational contexts. The 22 peer-reviewed papers demonstrate significant advances in combining immersive technologies with artificial intelligence to create more effective, engaging, and personalized learning experiences. From theoretical frameworks and methodological innovations to practical applications and empirical studies, the contributions reflect the diversity and dynamism of this emerging field.

The papers highlight several key trends and developments:

- The growing sophistication of immersive learning environments that leverage both AR and AI capabilities
- The emergence of augmented intelligence as a framework for enhancing educational processes
- The increasing importance of learning analytics and educational data mining in understanding and optimizing learning experiences
- The development of innovative approaches to integrate these technologies into various educational contexts
- The valuable insights gained from real-world applications and case studies

These proceedings also underscore the resilience and innovation of the educational technology community, particularly in Ukraine, where researchers and practitioners continue to advance the field despite ongoing challenges. The Academy of Cognitive and Natural Sciences (https://acnsci.org/), Kryvyi Rih State Pedagogical University, and Kryvyi Rih National University's successful hosting of AREdu 2024 demonstrates the community's commitment to maintaining international academic collaboration and advancing educational technology research.

Looking ahead, the field faces both opportunities and challenges. While the integration of AR and AI technologies shows great promise for transforming education, questions remain about implementation, scalability, and equity of access. Future research will need to address these challenges while continuing to explore the potential of these technologies to enhance teaching and learning across different educational contexts and disciplines.

The workshop's success in fostering dialogue and collaboration among researchers, practitioners, and technology developers bodes well for the future of AR and AI in education. We look forward to seeing how the ideas and insights shared at AREdu 2024 will influence the next generation of educational technologies and pedagogical approaches.

We had excellent presentations and fruitful discussions that broadened our professional horizons, and we trust that all participants derive immense satisfaction from this workshop. We look forward to the day when we will be able to meet again in person under more tranquil and peaceful circumstances.

Acknowledgments: We extend our sincere gratitude to the authors who submitted their papers and the delegates for their active participation and unwavering interest in our workshops, which have provided a platform for the exchange of ideas and innovation. Our heartfelt appreciation goes to the program committee members for their continuous guidance and to the peer reviewers, whose diligent efforts have substantially enhanced the quality of the papers by providing constructive criticisms, improvements, and corrections. We acknowledge and thank the authors for their significant contributions to the workshop's success.

Furthermore, we express our most profound appreciation to the CEUR-WS.org team (https://ceur-ws.org/), the only sponsor of the AREdu workshop series since 2018.

Declaration on Generative AI: During the preparation of this work, the authors used Claude 3 Opus in order to: Drafting content, Abstract drafting, Peer review simulation. After using this service, the authors reviewed and edited the content as needed and takes full responsibility for the publication's content.

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Immersive learning tools for teaching mathematics to high school students in general secondary education institutions

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Abstract

For the dynamic and sustainable development of an individual throughout life, the ability to shape a personal learning trajectory, communicate and collaborate in a team, prioritize life goals, and achieve them becomes a key aspect. Forming this kind of personality is one of the objectives of general secondary education institutions. Creating an educational environment that allows every student to realize their potential is impossible without innovative technologies, among which immersive technologies stand out as some of the most progressive. The use of immersive technologies in the educational process for high school students makes this process dynamic and engaging due to the interactivity of such technologies and their high level of visual representation. In Ukraine's secondary education system, the practice of implementing immersive technologies has demonstrated their effectiveness by increasing motivation to learn, which, in turn, has led to better academic performance. This study focuses on the use of immersive technologies in the teaching of mathematics to high school students in general secondary education institutions. Scientific literature highlights four main topics regarding the use of immersive technologies in education: 1) the impact of immersive technologies on learning outcomes; 2) the use of immersive technologies for learning and simulation; 3) the influence of immersive technologies on interaction and user engagement; 4) ethical and social implications of immersive technologies. In Ukrainian secondary education institutions, platforms for immersive learning include developments from both Ukraine and other countries. These platforms, such as AR Book, mozaBook, GeoGebra, and Desmos, are user-friendly, require no software installation, allow interaction with educational materials, and include both pre-designed tasks and the ability for students to create their own projects.

Keywords

immersive tools for teaching mathematics, high school students, general secondary education institutions, immersive learning platforms, AR Book, mozaBook, GeoGebra, Desmos

CEUR-WS.org/Vol-3918/paper004.pdf

1. Introduction

According to the State Standard for Specialized Secondary Education in Ukraine [1], one of the key objectives of teaching in academically oriented high schools is to develop students' competency potentials, reflected in learning outcomes.

Among the identified competency potentials essential for a high-quality and effective learning process in mathematics for students of academic high schools, we consider:

- *mathematical competency*, which involves the ability to develop and apply mathematical knowledge and methods to solve a wide range of real-world problems, model processes and situations using mathematical tools, and understand the role of mathematical knowledge and skills in personal and societal life;
- *information and communication competency*, which entails the confident, critical, and responsible use of digital technologies for personal development and communication; the ability to safely apply information and communication tools in education and other life situations while adhering to the principles of academic integrity.

AREdu 2024: 7th International Workshop on Augmented Reality in Education, May 14, 2024, Kryvyi Rih, Ukraine
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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

Given these priorities, there is an urgent need to develop innovative teaching approaches that foster the development of these competencies. One promising direction is the use of immersive technologies [2, 3], which have already proven effective in organizing learning processes in general secondary education institutions.

Immersive learning, which involves immersing students in an interactive environment, creates unique opportunities for developing problem-solving skills, critical thinking, and creativity [4, 5, 6, 7]. The use of immersive technologies is particularly relevant in teaching mathematics, as they enable the visualization of abstract concepts, the modeling of real-world processes, and the creation of interactive environments for the practical application of mathematical knowledge.

The purpose of this study is to analyze the potential of immersive technologies in developing mathematical and information-communication competencies among high school students in specialized classes of general secondary education institutions.

2. Literature review

The analysis of scientific studies on the use of immersive technologies in the learning process confirms that their first large-scale implementation in education began in the United States with the adoption of the National Education Technology Plan, titled *Transforming American Education: Learning Powered by Technology* [8]. According to this plan [8], the learning process should be based on the integration of educational courses with modern technologies to create engaging, relevant, and personalized learning experiences that reflect students' daily lives and future realities.

Although the first virtual schools appeared in the U.S. in the late 20th century, their initial purpose was to complement traditional education. Most virtual schools in the U.S. do not issue general secondary education diplomas or fulfill the traditional functions of schools. Instead, they offer online courses and related virtual services for schools [9].

Through intensive educational reforms, the U.S. addresses critical global pedagogical challenges, including [10]:

- updating the educational environment by leveraging advanced digital tools and cloud services for managing institutions and the educational process;
- modernizing educational content to align with scientific and technological progress;
- integrating immersive technologies into education;
- enhancing adaptive teaching methods, especially differentiation and personalized learning, and fostering the development of specialized skills.

The introduction of information and communication technologies (ICT) in education has driven systemic changes not only in the U.S. but also in Europe and Ukraine. The most significant transformation occurred during the COVID-19 pandemic, which accelerated the adoption of remote learning and increased the reliance on virtual platforms for education [11, 12, 13]. The largest platforms supporting immersive learning include the Immersive Education Initiative (http://immersiveeducation.org) and the Immersive Learning Research Network (iLRN) (http://www.immersivelrn.org). These platforms aim to help in creating educational environments enriched with immersive technologies.

According to an industry report on education [14], the targeted use of digital, particularly immersive, technologies in the learning process is essential for improving the education system. These technologies are grounded in:

- innovative pedagogical models, such as game-based learning, online laboratories, and real-time assessments, which enhance thinking skills, comprehension, creativity, imagination, and problem-solving abilities [15, 16];
- simulations, such as remote or virtual online laboratories, offering cost-effective and flexible access to experimental learning [17];

- international collaboration, which removes learning barriers and facilitates personalized learning paths, course selection, and technology integration;
- formative assessments, powered by technology, enabling teachers to monitor students' knowledge acquisition and adjust the learning process accordingly;
- e-learning, incorporating open educational resources and massive open online courses (MOOCs) to build personalized learning trajectories.

The recommendations of the European Union's Digital Education Action Plan (2021–2027) [18] and Goal 4 of the United Nations' *Transforming our world: The 2030 Agenda for Sustainable Development* [19] emphasize:

1. the necessity of creating innovative learning environments enriched with high-quality educational materials to mitigate learning losses;
2. the importance of enhancing digital competencies, including digital literacy, computer science education, awareness of immersive technologies (e.g., artificial intelligence), continuous upgrading of digital skills, and ensuring gender equality in digital education and careers.

As for the frontrunner in immersive technology integration, the U.S., it is worth noting that virtual schools are funded both by the government and private investors, facilitating the digitization of education and addressing learning gaps.

An analysis of scientific publications in databases such as Scopus and Google Scholar highlights the fields where immersive technologies are most actively used to enhance learning, including medicine, architecture and construction, design (e.g., urban planning), foreign language learning, shipbuilding and navigation, aviation, history and archaeology, and museum studies.

3. Results

The evolution of immersive technologies and their integration into the education system began with their use in foreign language learning, where they were established as a tool that enhances motivation and makes the learning process engaging. As early as the mid-1960s, it was proven that immersion in foreign language learning intensifies the educational process. According to Bloom's taxonomy of educational objectives, the application of immersive technologies affects the cognitive, affective, and behavioral aspects of learning, showcasing their versatility and effectiveness in improving literacy, creative thinking, communication, and collaboration [20].

The combination of immersive technologies with artificial intelligence has the potential to lead to innovative intellectual learning [21, 22]. Such technological integration enables the creation of more dynamic, interactive, and personalized learning environments, transforming traditional approaches into innovative ones [23].

This study focuses on the use of immersive technologies in teaching mathematics to high school students in general secondary education institutions. Scientific literature identifies four primary themes regarding the use of immersive technologies in education [24]:

1. the impact of immersive technologies on learning outcomes;
2. the use of immersion technologies for learning and simulation;
3. the influence of immersive technologies on user interaction and engagement;
4. the ethical and social implications of immersion technologies.

This article explores how teachers can leverage various immersive platforms in their professional activities.

3.1. AR Book

The AR Book platform was created in July 2022 in Ukraine and is supported by the Ministry of Education and Science of Ukraine as part of a project aimed at sustaining the educational process during wartime. This guarantees that all lessons available in the app align with the current curricula of Ukrainian general secondary education institutions.

Using this platform, every user gains access to interactive educational materials that incorporate elements of immersive technologies. The learning materials provided in the app are designed to be easy for students to understand and offer them opportunities to:

- build personalized, mobile learning trajectories;
- visualize educational content while independently studying topics through augmented and virtual reality tools;
- break down learning materials into manageable structural units tailored to their psychological characteristics;
- receive teacher support during the learning process and feedback for reflection.

The platform offers several benefits for teachers, including:

- the ability to prepare high-quality lessons regardless of the teaching format;
- tools to create interactive lessons using a lesson constructor, which includes various templates and customization tools, or to utilize lessons, quizzes, and experiments developed by other teachers and shared in the app;
- built-in artificial intelligence that allows teachers to analyze and adapt educational materials to meet the needs of individual students, monitor students' comprehension, and track their progress in mastering topics or sections;
- integration with any learning management system (LMS) used by Ukrainian general secondary education institutions, as well as with video conferencing services or calendar applications.

For general secondary education institutions, the platform ensures:

- the ability to monitor and analyze students' academic achievements;
- simple administration and compatibility with other systems used by schools to organize the educational process;
- a wide range of tools for effective teacher training in lesson organization.

To begin using the AR Book platform, teachers must register on its website (https://arbook.info/). They can log in using their credentials or Google account. After registration and entering their profile information, teachers can select a personal teacher workspace and access their profile tab in AR Book (figure 1).

Let us examine some elements of the platform that every teacher can access for free, and describe the potential use of the AR Book app for teaching mathematics in high school. The app is accessible to every student on any mobile device running iOS or Android.

1. **Calendar.** In the "Calendar" section, teachers can schedule their class activities according to their lesson timetable (figure 2).
2. **Lesson creation.** By clicking the event arrow in the calendar, the teacher can access templates for creating lessons or select a pre-made lesson (figure 3). When creating a lesson, teachers can include the following elements in their presentations: images, 360-degree images, text, slides, videos, experiments, VR experiments, and test assignments.
3. **Immersive educational materials.** These are available in the "All Content Types" section (figure 4). As the app is constantly updated with new educational materials, it is worth noting that for high school mathematics subjects, there is still a lack of fully developed content.

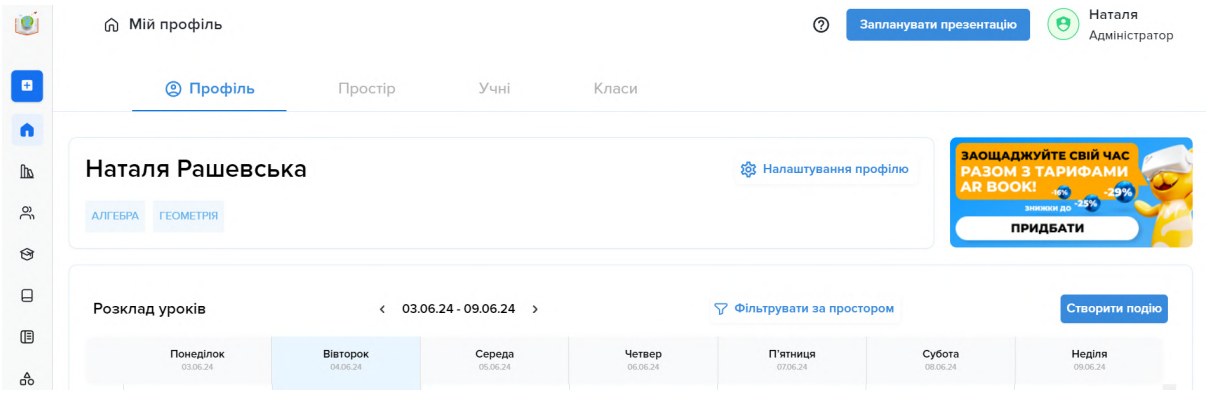


Figure 1: Getting started with AR Book.

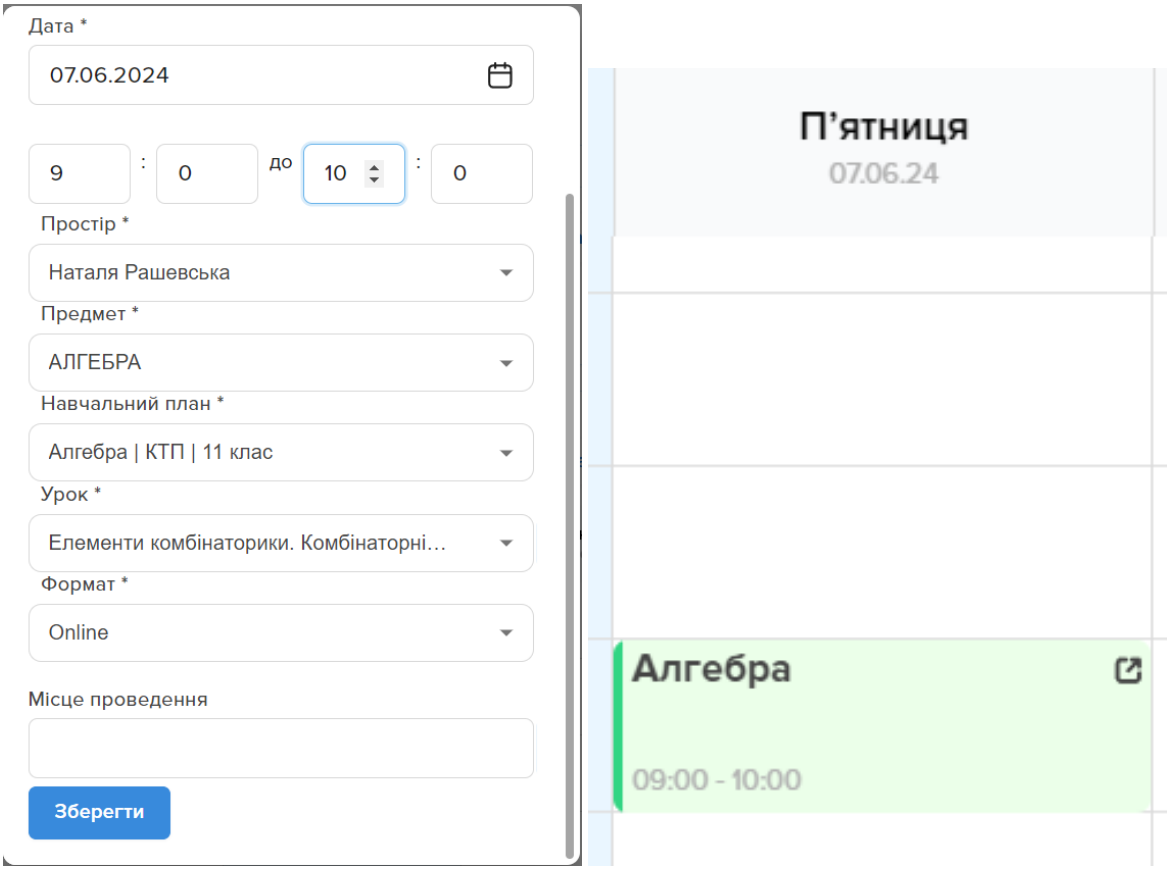


Figure 2: Creating an event in the calendar.

One key drawback of the platform is that only a relatively small portion of the material is available for free. Therefore, one way to address the issue of quality lesson preparation is to procure a school-wide subscription to the platform.

In the "Experiment" section, which corresponds to the practical portion of the curriculum, AR and 3D educational materials have been developed for the following mathematics topics for high school:

- **Probability theory and mathematical statistics:** combinatorics; the sum and product rules; statistics; combinatorics; and the frequency of random events.
- **Introduction to stereometry:** axioms of stereometry; basic concepts of stereometry; consequences of the axioms; and visualizing figures in stereometry.
- **Basic stereometry concepts:** points, lines, and planes; perpendiculars and obliques; the theorem

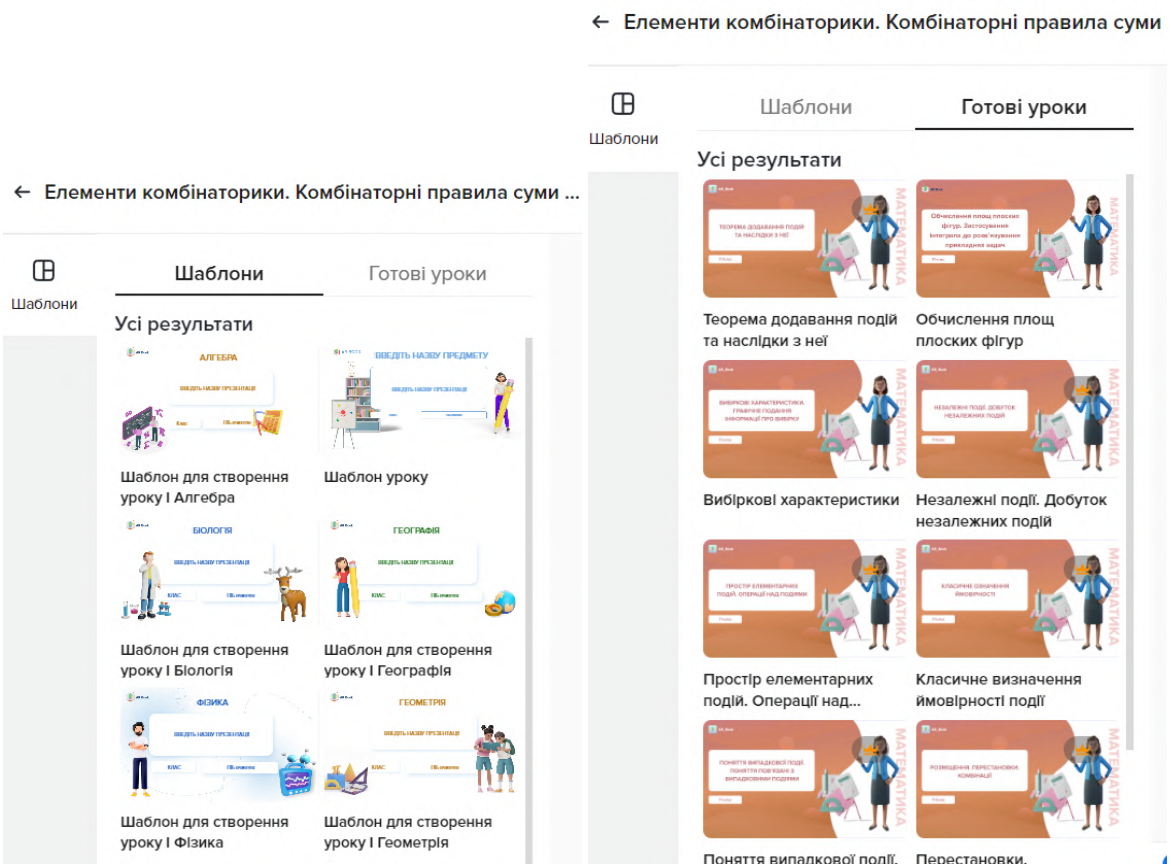


Figure 3: Lesson creation.

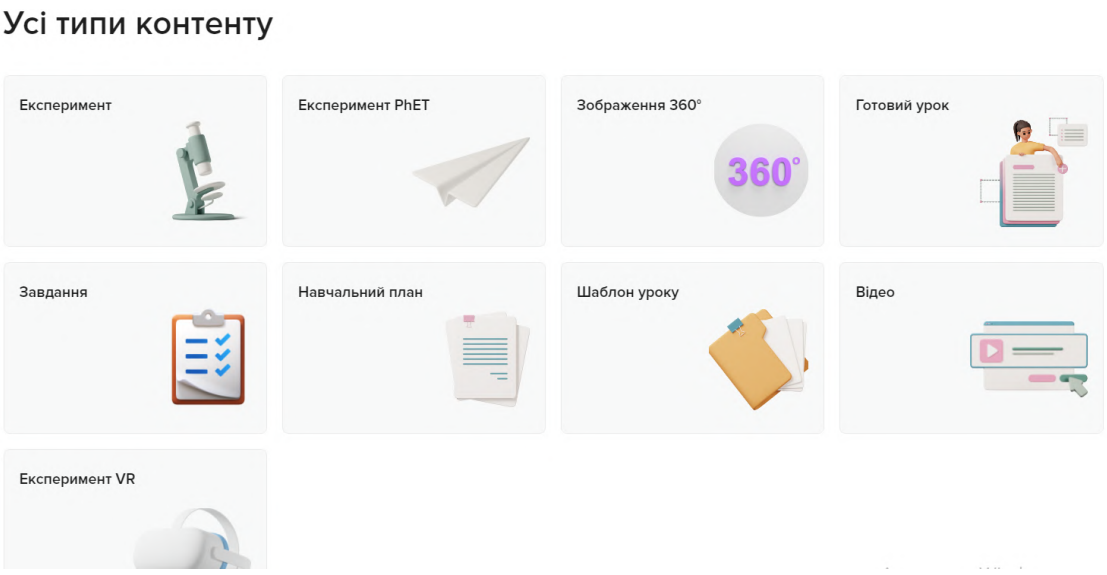


Figure 4: List of educational materials.

of three perpendiculars; mutual positions of lines in space; perpendicularity of lines in space; skew lines; dihedral angles; perpendicularity of planes; parallelism of planes; parallel projection; angle measurements in space; distances in space; parallel lines in space; and parallelism between a line and a plane in space.

- **Coordinate systems in space:** the coordinate system; Cartesian coordinates in space; plotting points in space by given coordinates; and calculating distances between two points in space.

- **Polyhedra:** volumetric geometric figures; prisms; prism sections; pyramids; parallelepipeds; the volumes of prisms, parallelepipeds, and pyramids; and regular polyhedra.
- **Solids of revolution:** cylinders; cylinder sections; the volume and surface area of cylinders; cones; the volume and surface areas of cones; sections of cones by planes; spheres and balls; and the volume and surface area of spheres.

The listed topics are not static and are continuously updated and modified. Each topic includes a visualized explanation of the material, test questions for self-assessment, and the ability to review the explanation multiple times. Some topics are available in the free version of the platform, but most are included in extended packages.

When the app was first launched in Ukraine's education system, access to AR and 3D learning materials was free of charge. We hope that over time, these resources will again become freely available for all Ukrainian teachers and students.

To differentiate between free and premium content, the platform uses specific labels for desktop and mobile applications:

 Material available in extended packages

 Material available in the free version

3.2. mozaBook

The mozaBook Platform by Mozaik Education has been made free for teachers and students in Ukraine since the beginning of the full-scale invasion. The app can be downloaded onto mobile devices via Google Play (https://play.google.com) and is compatible with Android and iOS operating systems. After downloading the app, users must register on the platform or on its website (https://ua.mozaweb.com/uk). During registration, users need to specify their region of residence, the educational institution they work at, and the classes they teach. Upon completing registration, teachers are provided with a personal workspace (figure 5) containing ample educational materials to organize lessons in various formats.

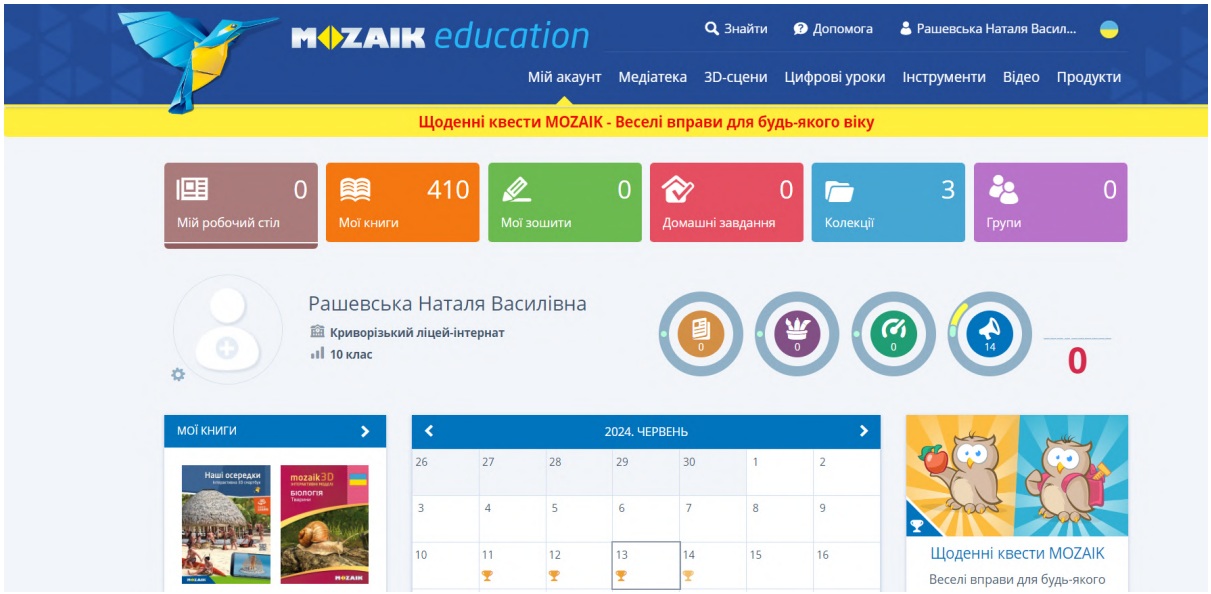


Figure 5: Initial screen of the platform.

Let us consider the possibilities of this platform in terms of immersiveness of mathematics learning material for senior high school students. The "3D Scenes" folder contains video applications on the following topics:

- **Probability theory and mathematical statistics**;

- **Basics of stereometry:** the positioning of planes in space, mutual arrangement of lines and planes in space, classification of geometric bodies based on various examples, angles in space, Cartesian coordinate system in space;
- **Polyhedra:** prisms, pyramids, Platonic solids, polyhedron nets, constructing their sections;
- **Solids of revolution:** solids of revolution around the axis of symmetry, 3D puzzles (a game to develop spatial perception), sphere, cylindrical bodies, conic sections, various types of surfaces, sphere, total surface areas;
- **Additionally:** Cavalieri's principle, interesting surfaces, polyhedra.

By choosing a 3D visualization of a topic, the teacher can provide students with a link for independent study or demonstrate it during a lesson, regardless of the teaching format. This can be particularly relevant when organizing instruction using one of the blended learning models, such as the flipped classroom model.

For enabling 3D visualization, a video player offered by the platform must be installed on a desktop computer or laptop.

Let us examine the topic of "The coordinate system in space". After launching the demonstration, it is possible to view the coordinate system in three variations: through axes, through coordinate planes, and with unit grid gradation (figure 6). The demonstration allows you to move the coordinate axes, visualize or hide labels.

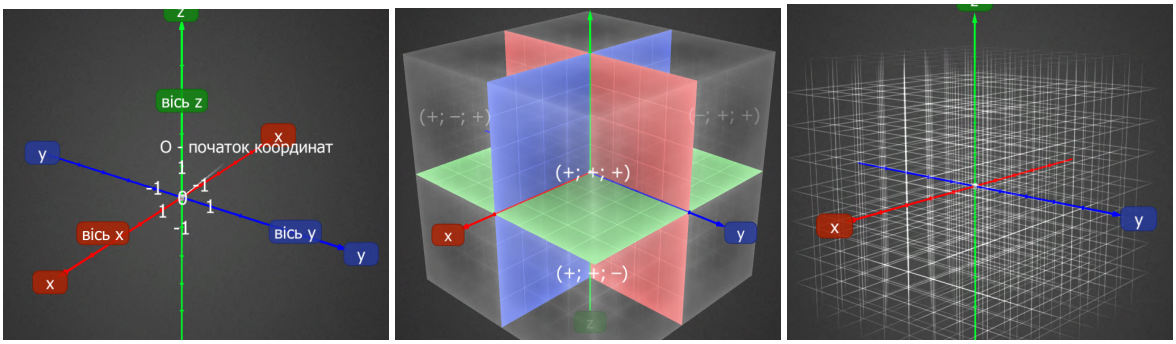


Figure 6: Various representations of the coordinate system in space

There is also a full demonstration of the theoretical material on the topic, a visualization of constructing a point in space based on given coordinates (figure 7), and a system of test tasks to assess the acquired knowledge on the topic (figure 8).

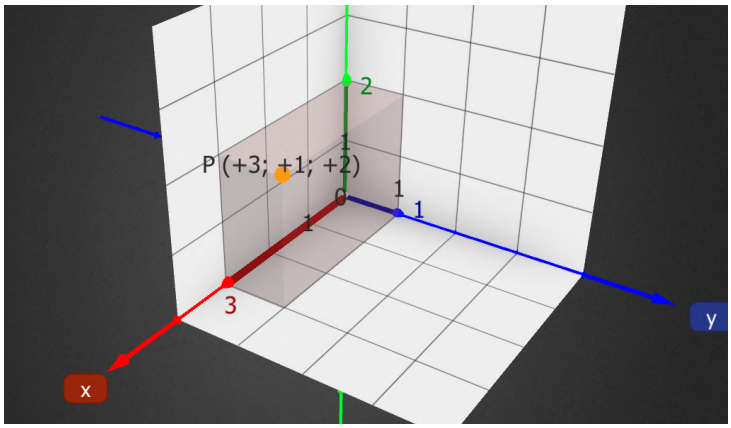


Figure 7: Constructing a point in space.

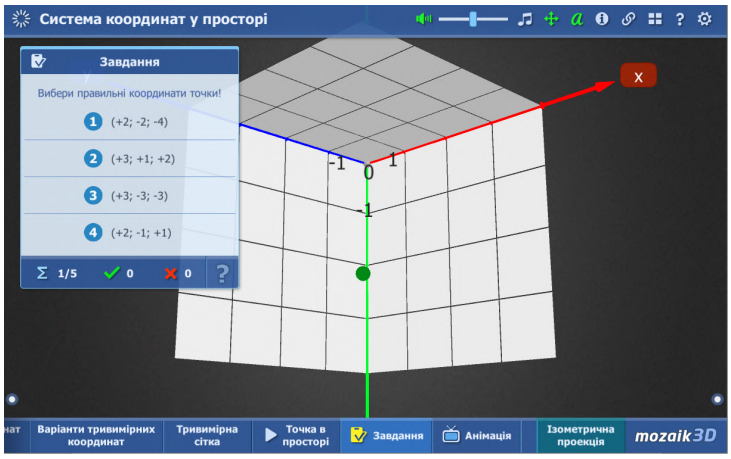


Figure 8: Test assignments.

3.3. GeoGebra 3D

GeoGebra 3D (https://www.geogebra.org/3d) is part of the GeoGebra Computer Mathematics System (CMS) (https://www.geogebra.org/), which can be downloaded as a standalone app for mobile devices or used directly on a desktop computer without registration, either with Internet access or by downloading specific applications. Additionally, users can register to save 3D constructions or other examples, which will be stored in the cloud. Registration in GeoGebra CMS not only allows saving completed constructions or studies but also enables simultaneous collaboration between teachers and students on a project.

This computer mathematics system is well-known in the educational community and does not require extensive review.

When studying algebra in grades 10–11, it is advisable to use the app for graphing functions, exploring them, or visualizing the calculation of the area of a flat figure. More interestingly, GeoGebra 3D can be used for constructing geometric solids, creating cross-sections of these solids, and gaining a comprehensive understanding of stereometry.

The app's initial workspace includes a three-dimensional Cartesian coordinate system and a set of tools on the left side (figure 9).

The coordinate system, along with the depicted solids, can be explored within a 360° range.

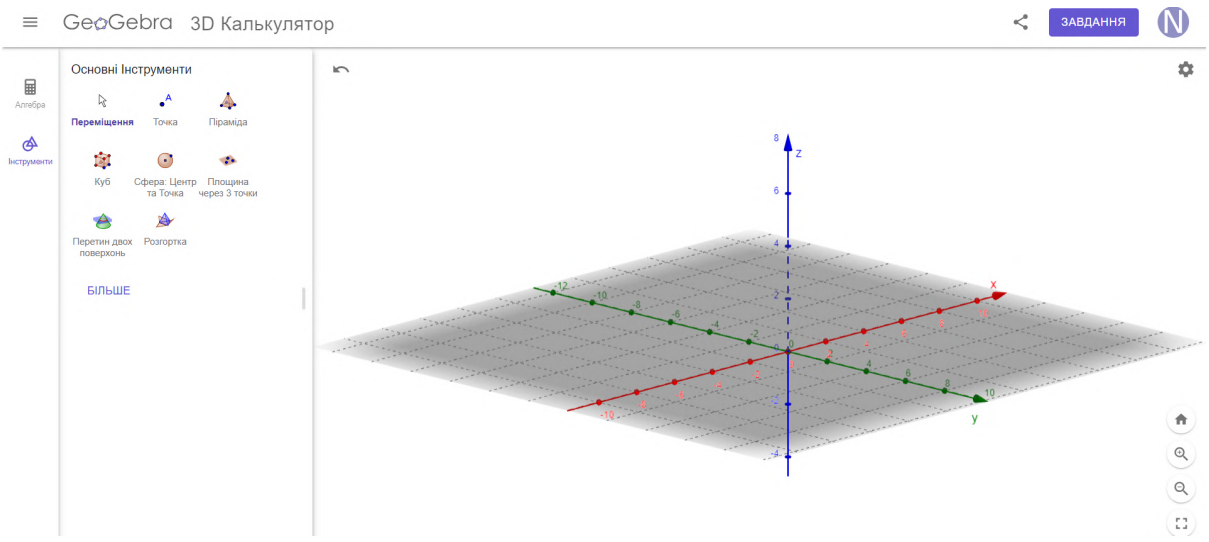


Figure 9: Starting work in GeoGebra 3D.

In the top-right corner, a gear icon allows access to coordinate system settings: showing axes, displaying grid lines, selecting scale, and other adjustments. You can also choose the language, set font sizes, determine whether labels are displayed, and specify the range for constructing geometric solids.

When studying geometry in senior grades, the app can be applied for the following types of tasks:

1. **Working with the three-dimensional Cartesian coordinate system** – constructing points and planes. Points can be created by specifying their coordinates or through a step-by-step explanation of their construction. Planes can be constructed: a) by three points, by a point and a line, or by two intersecting lines; b) by a plane parallel to a given one; c) by a plane perpendicular to a given one;

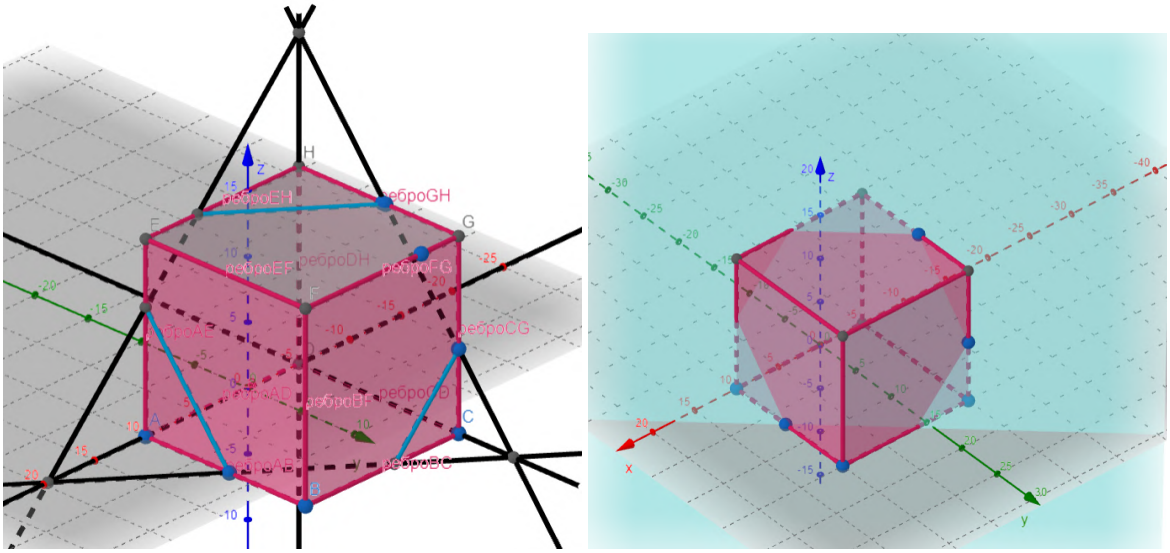


Figure 10: Constructing cross-sections

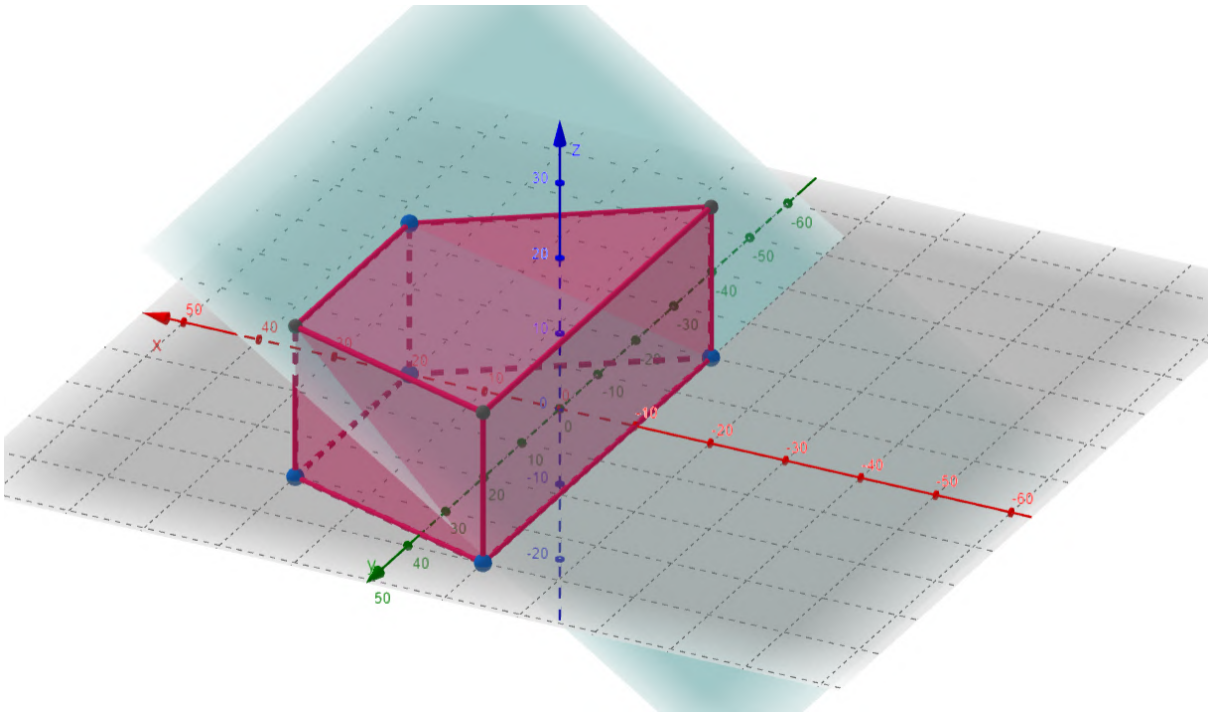


Figure 11: Visualization of geometric solids.

2. **Constructing cross-sections of solids** – a critical concept in 10th-grade geometry. The app's tools make it possible to visualize the entire construction process, make it dynamic, and illustrate it from different angles (figure 10).
   It is worth noting that cross-sections can be constructed either by using the traces method (Fig. 10a) or by utilizing a built-in tool on the app's toolbar (figure 10b).
3. **Constructing geometric solids.** The app allows for the creation of various geometric solids, cross-sections, the display of angles between faces and edges, and the study of solid properties (figure 11).

Additionally, the app contains a sufficient number of resources that can be utilized during the learning process, enabling the personalization of student education (https://www.geogebra.org/t/solids?lang=uk – figure 12).

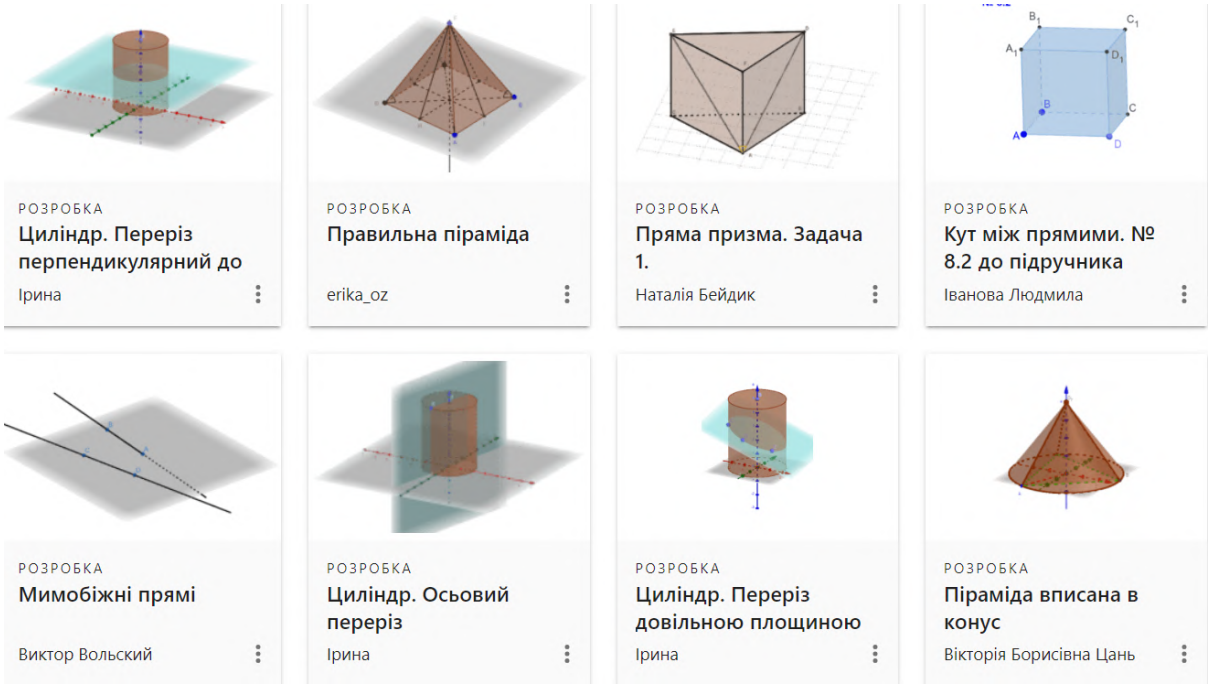


Figure 12: Educational materials with 3D visualization.

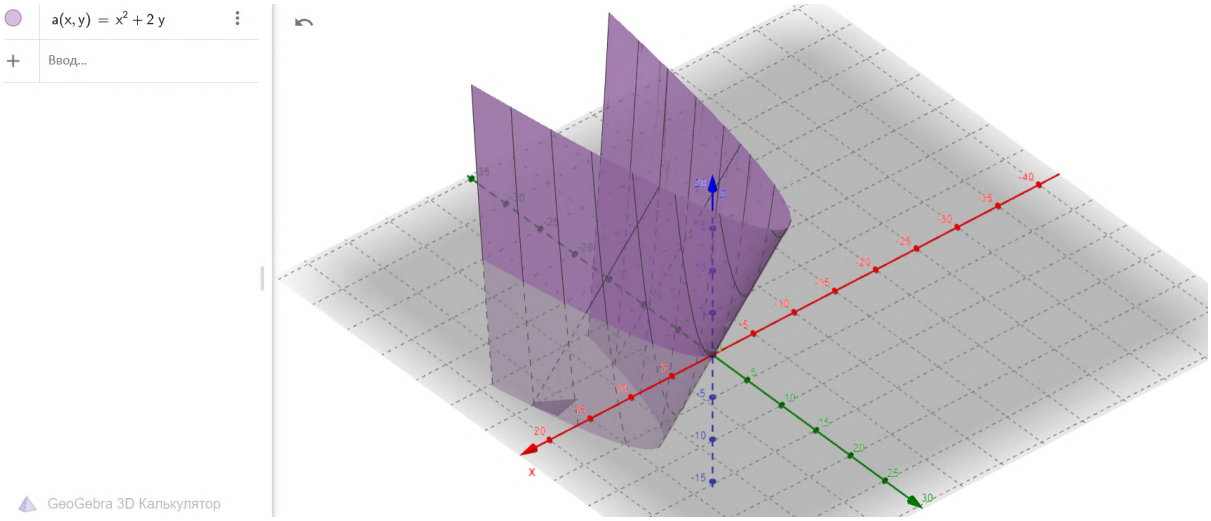


Figure 13: Working with surfaces.

For students specializing in mathematics, the app can be used to work with various surfaces. The ability to visualize and study surfaces provides opportunities for developing spatial thinking and understanding one's position in space (figure 13).

3.4. Desmos

For organizing interactive learning in a blended learning model, it is also advisable to use the Desmos graphing calculator, which is currently actively recommended for addressing students' learning gaps.

Desmos is a graphing calculator available on any device, whether mobile or desktop (https://www.desmos.com), with the option to register in the program or work online.

Although this graphing calculator is more suitable for middle school students, let us consider its potential applications in senior high school.

The mathematics section "Functions, their analysis, and graph construction" in the 10th-grade algebra course has always posed challenges for students. It is important to note that the topics in this section are actively tested during external independent assessments (ZNO) and the national multi-subject test (NMT). This means that studying these topics requires ample visualization of the learning material and a thorough understanding of all function properties.

The graphing calculator provides a set of pre-designed explorations that can be conducted with functions during its use, as well as the ability to independently select functions for analysis.

More engaging for senior high school students is the Desmos 3D Calculator, which enables the creation and exploration of geometric solids by transitioning from flat constructions to three-dimensional models.

4. Conclusions and prospects for further research

The reviewed platforms for organizing mathematics education for senior high school students using immersive technologies do not exhaust all the advantages and possibilities of immersive learning but rather outlines key directions for further research.

1. Integration of immersive technologies into the Ukrainian education system is necessary for their systematic use, as they enable deep engagement in the learning process through visualization of educational material.
2. Development of adaptive curricula for studying subjects such as mathematics, physics, chemistry, geography, and history will create conditions for personalized learning trajectories for each student.
3. Organizing a high-quality learning process based on immersive technologies requires the development of a methodological system for the most challenging subjects for students—those in the natural sciences and mathematics.
4. Special attention should be given to the training of teachers, who will be able to implement immersive learning in general secondary education institutions, develop their digital competencies, and foster these competencies in their students.

Declaration on Generative AI: The authors have not employed any Generative AI tools.

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Enhancing personal financial management skills through a machine learning-powered business simulator

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Abstract

Effective personal financial management is a critical life skill for all individuals, irrespective of their profession. A survey conducted among university students in Ukraine revealed a lack of sufficient financial literacy and highlighted the need to incorporate personal finance education into curricula. Business simulators present a promising solution to bridge this gap. This paper introduces a novel web-based business simulator equipped with machine learning capabilities to facilitate the development of personal financial management skills. The methodology for utilising the simulator, including its content, objectives, formats, methods, and tools, is elucidated in detail. The key features and sections of the simulator are described, along with the specific personal finance management skills it aims to cultivate. To enhance the simulator's effectiveness, elements of machine learning, particularly reinforcement learning, have been incorporated. The simulator is designed to cater to a wide audience, from school-aged children to adults, and can be integrated into economics courses at both secondary and tertiary education levels in Ukraine. The paper concludes with a discussion on the future prospects of using such simulators to develop managerial and financial competencies among students from diverse specialities.

Keywords

personal financial management, business simulator, machine learning, reinforcement learning, financial literacy

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1. Introduction

Personal financial management is a vital skill that everyone should possess, regardless of their profession or background. It involves the effective management of one's financial resources, including income, expenses, savings, investments, and debts.

The importance of developing personal finance competency has been widely acknowledged in international research. Lusardi [1] discussed the influence of financial literacy on the well-being of people worldwide and the need to recognise it as a fundamental right and universal need. Lusardi et al. [2] demonstrated that 30–40% of retirement wealth inequality in the USA is associated with the level of financial literacy alone. Urban et al. [3] concluded that high school financial literacy courses have a significant impact on lower default rates and better credit scores.

The use of business simulations in education has become increasingly common, with applications ranging from practical training, such as flight or combat simulations, to economic, managerial, and financial domains. Researchers have studied the pedagogical significance of this technology-enhanced educational method. Hernández-Lara et al. [4] concluded that business simulations have a positive impact on generic competencies, while Farashahi and Tajeddin [5] confirmed their effectiveness in a comparative study. The evolution of technologies has enabled the development of immersive, attractive,

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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

and highly functional business simulations for various use cases, from elementary schools to lifelong learning establishments. Korgin [6] provided evidence of the effectiveness of simulation games for improving basic arithmetical operations literacy in children, while Palan [7] studied the criteria and approaches for selecting business simulation software for asset market experiments in higher education.

The analysis provides evidence of the effectiveness of using business simulations in education and the need for further development of business simulations for economic and financial literacy development, assessment, and the study of their behavioural aspects.

The *purpose of this article* is to describe the methodology for using a business simulator with machine learning elements to develop personal finance management skills.

2. Results

An analysis of existing simulators [8, 9] revealed that most simulation software is designed for specific areas of finance in countries with developed financial markets. Based on these findings, this work presents an experiment in developing a more generalised simulator for countries with less developed financial instrument markets.

Consequently, the authors developed a web-based business simulator [10, 11, 12] to foster personal finance management skills. The methodology for using this simulator, which incorporates machine learning elements, is presented in the following sections.

The proposed methodology encompasses the purpose and content of the application, as well as the forms, methods, and tools employed. It is focused on the expected outcome: improved personal finance management skills through the use of a business simulator with machine learning elements.

The purpose of using the simulator is to develop personal finance management skills, while the content involves enhancing the teaching process of normative disciplines through its integration.

The methodology includes two key methods for utilising the simulator:

1. *Adaptive learning*. The simulator creates a game-like process, known as the examination cycle, in which users encounter problems corresponding to their current competence level at each stage. As users progress through the simulation, they gain access to new personal finance management tools that could not be effectively used at previous competence levels. This approach requires users to iteratively master increasingly complex knowledge, skills, and abilities, and apply them in situations resembling real-life scenarios. Users can explore previously unfamiliar tools and situations or those of additional interest to them, considering their life cycle stage, field of activity, or current problems and interests.
2. *Situational modelling*. The simulator is based on realistic simulations of common and specific situations in personal or family finance management. It begins by modelling the creation of a diversified currency and financial basket storage forms, then progresses to more complex tools, such as credit and deposit operations with varying time parameters, payment schedules, and provision forms. The simulation's realism is ensured by the presence of probabilistic events with positive or negative impacts of different monetary values on the user's personal finances. Non-financial investment transactions are introduced as the next step in familiarising users and developing their competence in personal finance management.

The main forms of conducting training sessions using the simulator within the framework of this methodology include:

- Introductory classes for teachers and facilitators on the simulator's functionality, modes, features, analytical capabilities, and means of scientific research on the effectiveness and adaptability of the user competence development process;
- Autonomous and group independent work with the simulator, aimed at both independent in-depth or convenient pace learning through the training and game plot, and joint learning activities of user groups and facilitators, with or without competitive elements;

- In-depth analysis of simulator situations can take place in face-to-face or remote formats with individual students or groups, focusing on additional elaboration of situations, behavioural and psychological aspects, or financial instruments that cause difficulties, misunderstanding, or attract additional user interest.

The tools for developing personal finance management skills provided in the proposed methodology include computers, smartphones, and tablets with Internet access, the business simulator with machine learning elements, and teaching materials.

The expected result of the proposed methodology is the formation of personal money management skills at a high level and the acquisition of skills to successfully apply the business simulator with machine learning elements to perform practical work.

Within the framework of this methodology, different forms and methods of using the simulator are offered, such as:

- Organisation and development of the simulator to develop personal finance management skills;
- Sessions using the simulator to simulate socio-economic situations corresponding to the lesson topic;
- Organisation of thematic economic training using the simulator;
- Visualisation of economic and behavioural concepts;
- Using the simulator as a means of targeted in-depth problem-based learning;
- Using the simulator as a means of organising assessment.

The main features of the simulator, presented in different sections (figure 1), include:

1. Current account management options.
2. Savings management options.
3. Deposit management options.
4. Credit management options.
5. Non-financial investment management options.
6. Information on changes in current accounts that have occurred in the last week.
7. Analytical information on the dynamics of changes in current account funds, savings, and investments.
8. Information on current exchange rates.
9. List of recent transactions made on current accounts.

The simulator facilitates the formation of knowledge, skills, competencies, and personal attitudes towards:

- Using a diversified list of currencies.
- Forming a widely-acknowledged standard of emergency savings and assessing readiness for longer-term investment.
- Using basic saving and investment instruments available in a wide range of countries, such as deposits (deposit certificates), real estate, and business investments, and understanding their specific characteristics.
- Debt management and forming a personal behavioural attitude towards using debt as a constructive investment leverage.

To enhance the effectiveness of the simulator, machine learning elements, particularly reinforcement learning, have been applied. Reinforcement learning (RL) is a type of machine learning in which an agent directly examines environmental data, receives rewards, and sets policies for optimal action (figure 2). The goal of RL is to find the optimal policy that maximises the expected amount of future rewards [13].

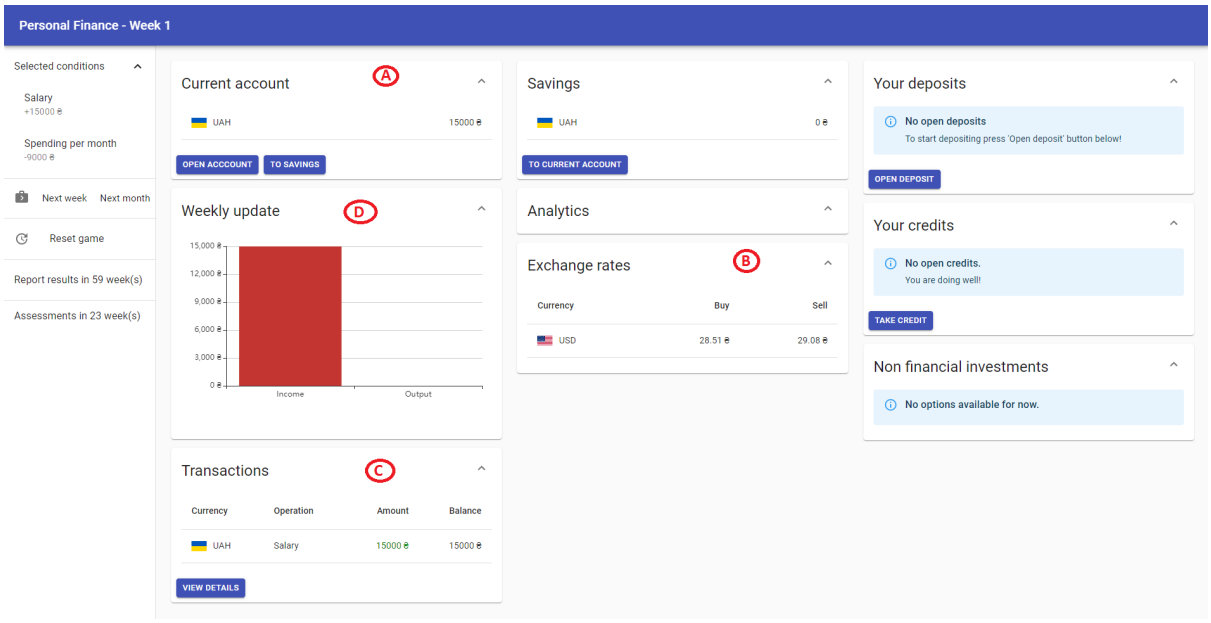


Figure 1: Business simulator.

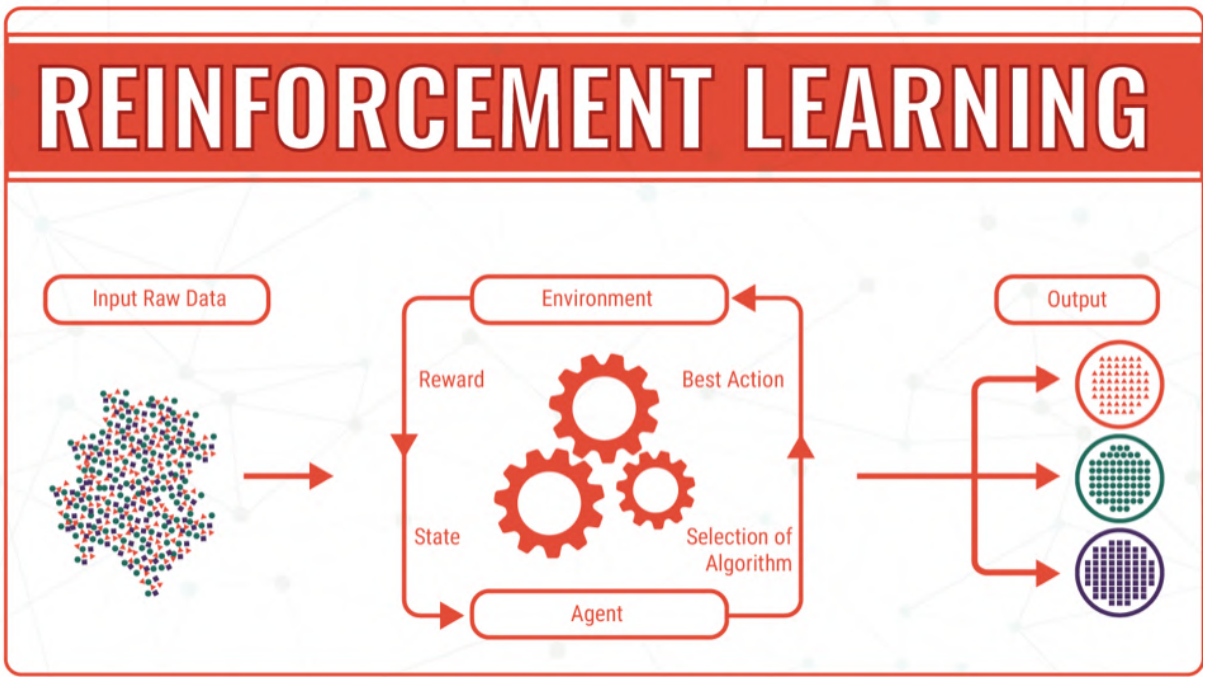


Figure 2: The principle of operation of the model of training with reinforcement [13].

$$Q^{new}(S_t, A_t) \leftarrow (1 - \underbrace{\alpha}_{\text{learning rate}}) \cdot \underbrace{Q(S_t, A_t)}_{\text{current value}} + \underbrace{\alpha}_{\text{learning rate}} \cdot \Big(\underbrace{\underbrace{R_{t+1}}_{\text{reward}} + \underbrace{\gamma}_{\text{discount factor}} \cdot \underbrace{\max_a Q(S_{t+1}, a)}_{\text{estimate of optimal future value}}}_{\text{new value (temporal difference target)}} \Big)$$

Figure 3: Q-learning algorithm.

One of the algorithms used in reinforcement learning is Q-learning, which aims to learn a strategy that informs the agent about the best action to perform in a particular state S. The algorithm contains elements such as the reward received (r_t), the learning pace (α), and the depreciation ratio (γ) (figure 3).

The open-source library SharpRL [14] was chosen to provide the basic functionality for developing a reinforcement learning environment based on the Q-learning algorithm. The program for defining personal financial strategies is a console application that involves setting certain parameters, such as the number of simulation passes in training mode, the number of simulations in policy adherence mode after training, the duration of the simulation in weeks, and the user's monthly income and expenses in a specific currency.

Experiments were conducted to determine the optimal ratio of initial parameters, and it was found that the best results were obtained when the number of simulation passes in both training and policy adherence modes was close to 1000. Increasing these figures did not significantly improve the results (figure 4).

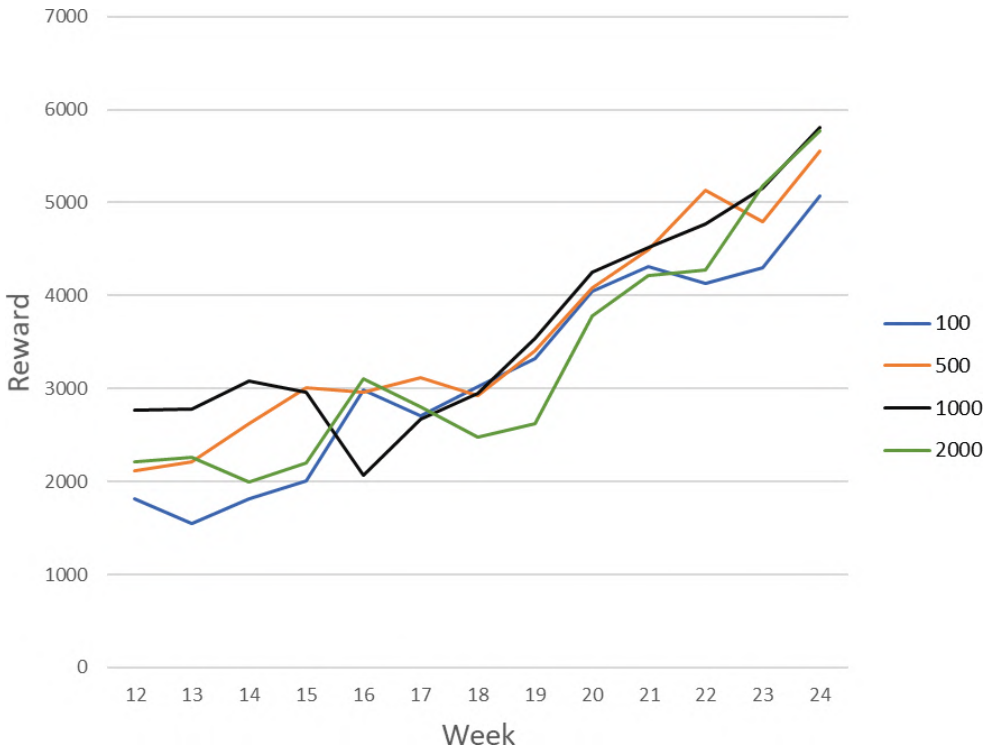


Figure 4: Results with different number of epochs of training in the mode of adherence to the trained model.

To test the trained model, the results of the system were compared with the average results of real users in the developed simulator over a 54-week period. It was found that the system consistently outperformed the average user results (figures 5, 6, 7, 8).

The graphs depicting the reinforcement learning model results exhibit jumps, particularly when higher incomes and a large difference between income and expenses are involved. This is due to the specific rules described to train the model, ensuring that the virtual agent system follows the best path. For example, if an agent opens a 3-month deposit, the deposit will be closed automatically after this period, significantly affecting the user's reward for that week. However, the system learns and "understands" where to invest or save, leading to sharp increases in performance, as evident in the graphs. Such behaviour is not observed in the graphs representing real user results, indicating users' lack of awareness of effective personal finance management strategies within the developed simulator.

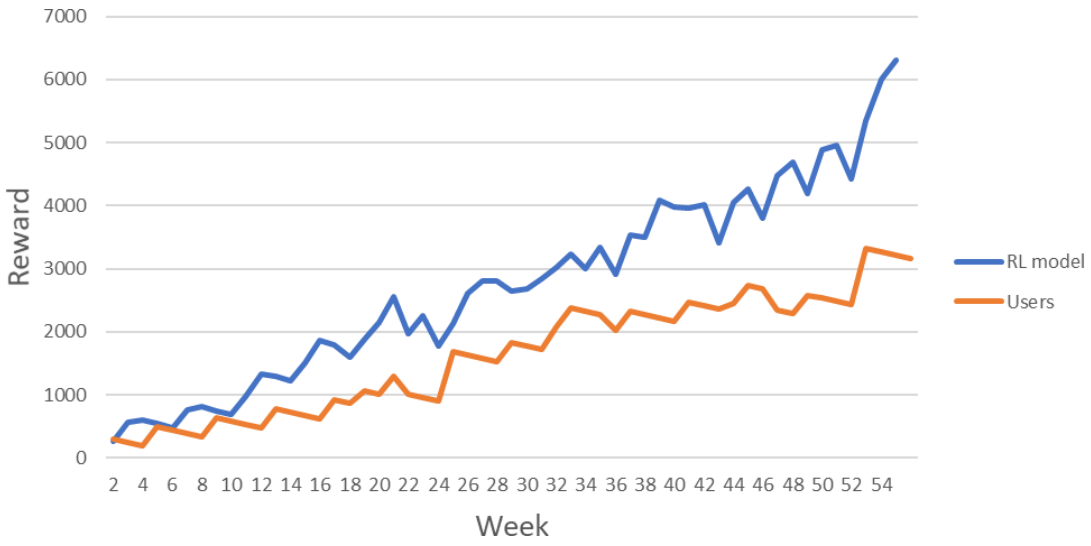


Figure 5: Comparison of model and user results with parameters of UAH 10,000 income and UAH 6,000 costs.

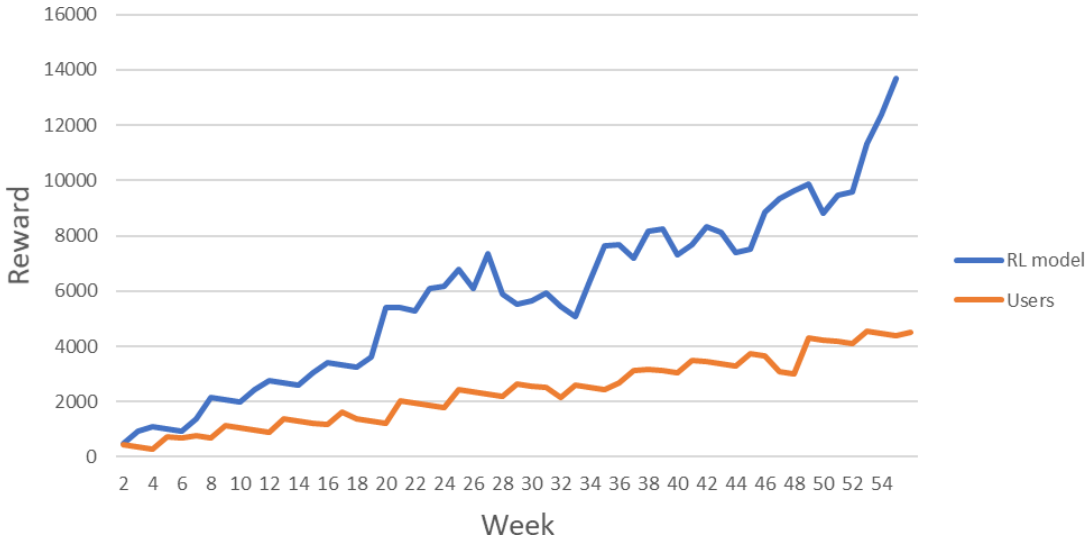


Figure 6: Comparison of model and user results with parameters of UAH 15,000 income and UAH 9,000 costs.

3. Conclusions

Economic processes are a new topic for research into the possibilities of applying the full potential of machine learning. Scientists worldwide are making initial attempts to reproduce such processes programmatically to use artificial intelligence to find solutions and answer various economic questions.

The proposed developed software package consists of two parts: a personal finance management simulator and a system for determining effective financial strategies, which utilises reinforcement learning opportunities.

The simulator can be used in the future to teach elements of personal finance management to people who are not sufficiently knowledgeable in this field. Moreover, the web application can be useful even for school-aged children, complementing the educational process within economic courses not only in higher education institutions but also in secondary education institutions in Ukraine.

When constructing a methodology for using a business simulator with machine learning elements to develop personal finance management skills, it is advisable to consider various types, scopes, methods of placement, and purposes of using business simulators. The use of a business simulator with machine learning elements is expedient and contributes to an increase in the efficiency of the educational process,

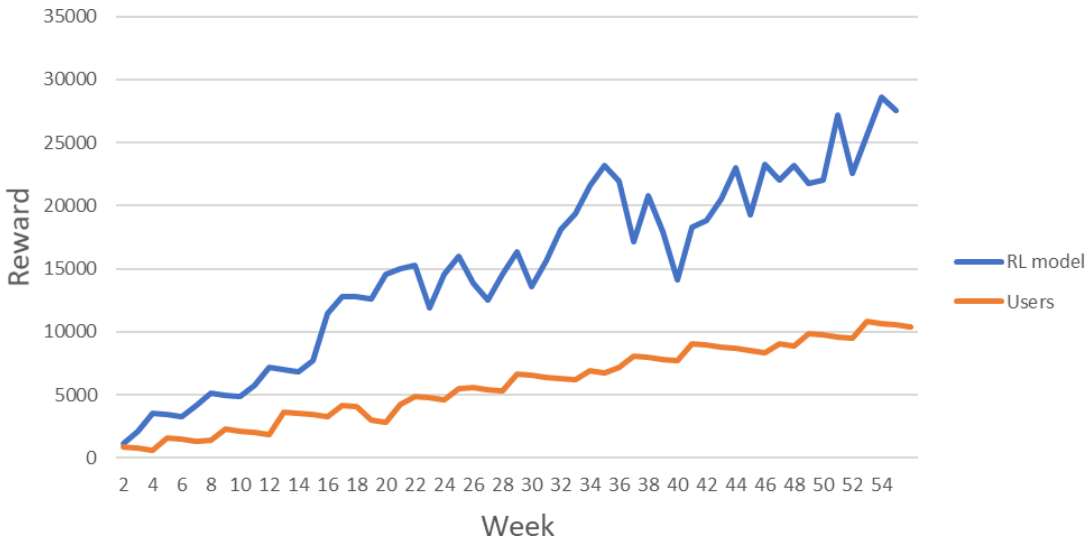


Figure 7: Comparison of the results of the model and users with the parameters of UAH 30,000 income and UAH 15,000 costs.

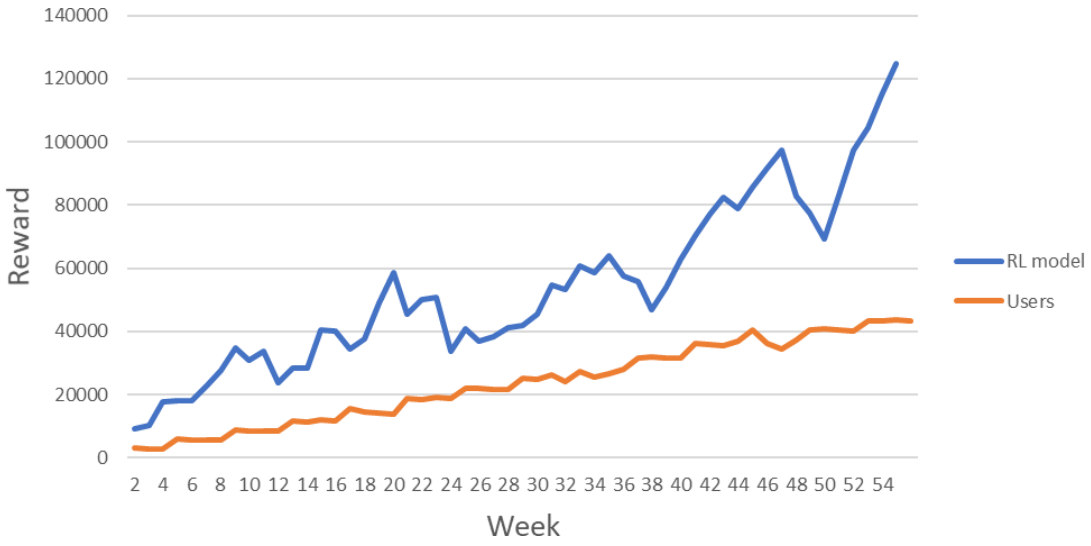


Figure 8: Comparison of the results of the model and users with the parameters of UAH 100,000 income and UAH 30,000 costs.

the formation of personal finance management skills, and the development of a steady cognitive interest in students' educational activities. The application of the author's methodology will improve and supplement the educational process in higher education by including a business simulator with machine learning elements.

Additionally, prospects for further study include the selection of different simulators of this type, the possibility of using such simulators to develop managerial and financial competencies of students in various specialities, as well as the development of an appropriate methodology and testing its effectiveness. In the future, the authors plan to develop guidelines for teachers on using a business simulator with machine learning elements to develop personal finance management skills in the educational process of higher education.

Declaration on Generative AI: During the preparation of this work, the authors used Claude 3 Opus in order to: Improve writing style, Abstract drafting. After using this service, the authors reviewed and edited the content as needed and takes full responsibility for the publication's content.

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Bridging minds and machines: AI's role in enhancing mental health and productivity amidst Ukraine's challenges

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Abstract

The article explores the convergence of human intelligence with artificial intelligence, emphasizing its potential to enhance education in the realm of mental health. This synergy is especially crucial in Ukraine, particularly within its educational institutions, following the pandemic and amid wartime conditions. The article delves into the concepts of "digital mental health" and "e-mental health," shedding light on the significance of "mental health technology" and "digital mental health." It also examines the standards for university courses in mental health technologies and introduces a variety of mental health apps, encompassing apps, wearables, platforms, data analytics resources, and other tools. The article underscores the importance of integrating artificial intelligence into both the education and economic sectors. It provides a comprehensive account of an experiment integrated into a standard university curriculum, involving master's psychology students at a pedagogical university. The results and conclusions of this experiment are thoroughly detailed. Moreover, the article investigates the impact of transactional distance on the learning experience of students pursuing mental health technology courses in an online format at Kryvyi Rih State Pedagogical University during the 2023-2024 academic year. Indicators of the transaction distance of the sample are researched and presented in detail. The influence of evaluation, satisfaction and their interaction on the level of transactional distance is analyzed too. Applied logical and statistical tests were used, in particular, using the Pearson test for correlation analysis. The study's findings affirm the critical role of synergizing human and artificial intelligence in addressing pressing challenges, enhancing mental health education, honing data analysis skills, and shaping a brighter future for well-being.

Keywords

human-AI synergy, digital mental health, e-mental health, mental health technology, artificial intelligence in education, transactional distance, online learning, higher education, mental health apps, wearables, data analytics, psychological education, university curriculum, pedagogical innovations, Pearson correlation analysis, wartime education, Ukraine, sustainable well-being, mental health pedagogy, education technology, digital transformation

1. Background context

The fusion of human intellect and artificial intelligence algorithms has ushered in a realm of unsurpassed opportunities for advancing mental health technologies and treatments in an age that is defined by rapid technological progress and data-driven decision-making processes in psychotherapy. This article delves into the vast potential of collaborative synergy between humans and AI that focuses on two key realms: enhancing crisis online counselling education of psychologists in war conditions in Ukraine and data-driven decision making within HEI.

Amidst the backdrop of the Ukrainian conflict from 2022 to 2024, numerous enterprises and institutions operating within Ukraine have been confronted with significant challenges. They not only grapple with adapting to volatile work conditions and employee needs but also contend with the enduring effects

AREdu 2024: 7th International Workshop on Augmented Reality in Education, May 14, 2024, Kryvyi Rih, Ukraine
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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

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of the COVID-19 pandemic [1, 2]. The once-prosperous Ukrainian economy of 2021, a driving force behind the nation's growth, has been particularly susceptible to disruptions caused by rolling blackouts, shelling incidents, and labor displacement.

Recognizing the substantial impact of professionals' mental well-being on overall business performance, there arises a critical need for future organizational psychologists to possess skills in monitoring mental health, resilience, and relevant organizational metrics. Addressing these challenges requires an urgent optimization of psychology curricula to align with the demands imposed by the Ukrainian war context.

To tackle these pressing issues, artificial intelligence capabilities come into play. By leveraging AI-based tools, we can overcome hurdles related to tracking and interpreting vital mental health indicators. Moreover, equipping HR and psychologists with practical skills in utilizing psychometric data is essential. This innovative approach not only enhances our understanding of mental health outcomes but also empowers enterprises and institutions to make well-informed decisions crucial for supporting employee well-being and overall efficiency amidst wartime conditions in Ukraine.

2. Literature review

2.1. Mental health technologies for online crisis counselling

Mental health technology is a multi-faceted field that represents the convergence of technology and mental well-being [3]. This broad vision includes various digital innovations carefully designed to support and improve mental health care and overall psychological well-being. At its core, mental health technology is a catchall term that covers a wide range of digital tools, apps and devices, where each of them is strategically designed to serve different aspects of mental health care [3]. These innovations span the entire mental health spectrum [4], from the critical areas of prevention and early intervention to treatment and ongoing support (figure 1) [5].

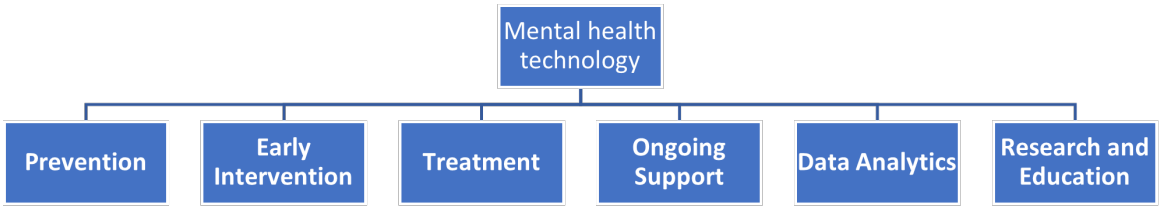


Figure 1: Mental health spectrum of technologies.

Firstly, prevention is at the fore of mental health technology, offering proactive tools and platforms designed to prevent the occurrence of mental health problems [6]. For example, these may be stress-reduction apps, mood-tracking software, and digitally attentive programs that help people build resilience and maintain mental balance. All this tools should supported by statistical analisis and recomendations from psychologist.

Secondly, recognizing the importance of early detection and interference, mental health technologies offer screening and assessment tools that can identify potential mental health problems in their initial stages [7]. These tools enable intervention and access to appropriate resources of support promptly, mitigating the severity of conditions and improving prognosis.

In addition, some researches state that AI can be used as an alternative data source in scientific research, in particular to collect synthesized prior knowledge on the topic under study. Through a research process to study the impact of the global health crisis caused by COVID-19 on education, based on the joint analysis of human intelligence and artificial intelligence [8], it was demonstrated that the use of such technologies can take the process of scientific research a step forward and accelerate the scale and speed of knowledge production for the benefit of humanity [9].

Thirdly, digital mental health solutions offer a variety of options in the treatment space [10]. There are evidence-based digital therapies such as cognitive behavioral therapy (CBT) and dialectical behavior therapy (DBT) delivered through mobile apps and online platforms [11] as well as individual and group therapy zoom-meetings, chat-bots. These solutions allow people to participate actively in treatment and recovery.

Further, after the initial stages of treatment, mental health technology continues to play a decisive role in supporting well-being [12]. Supportive communities and peer networks promote a sense of belonging and reduce feelings of isolation. Wearable devices and monitoring tools can track biometric data, helping individuals and their healthcare teams path progress and make data-driven adjustments to treatment plans [13].

Moreover, the use of big data and advanced analytics is a growing aspect of mental health technology [14]. It becomes possible to identify trends, predict mental health crises and adapt measures on a larger scale with the help of combining and analyzing large data sets. This data-driven approach has the potential to revolutionize mental health care.

Mental health technology also supports research by providing a platform for studying mental health patterns and treatment outcomes [15]. It is a valuable educational resource for both mental health professionals and the general public, offering ideas, guidance, and training materials.

Although AI offers benefits in academic environments and mental health research, it has evoked a mixture of awe and apprehension among educators and researchers, prompting efforts to understand and potentially mitigate its impact. There are some studies that seek to illuminate the current perceptions of AI in academic literature, exploring its implementations and the perceived risks it may pose to the educational landscape. Disputes about the ethics of using AI have been going on for several years now, and even legal aspects are being discussed. However, its influence continues to grow, with researchers studying both the positive and negative aspects of its use for educational and research purposes [16].

Last but not least, the human brain can acquire knowledge, generate new ideas and make decisions based on internal data and machines, which is known as machine learning [17, 18]. At the same time, neural networks are a tool for their implementation and imitate human skills [19, 20]. Despite the ethical and social impact of rapidly developing AI, it paves the way for more research in a multilingual society [21].

2.2. Standards for university courses of crisis online counselling with implementation mental health technologies

Artificial intelligence is rapidly transforming many fields, including psychology. AI has the potential to improve psychological research, practice, and education. For example, AI can be used to develop new diagnostic tools, create personalized treatment plans, and improve the delivery of mental health services. Notwithstanding, for psychologists to fully embrace AI, they need to be trained in the technology. A recent study found that psychology students are interested in AI, but they need more training in order to use it effectively. The study also found that students are concerned about the ethical implications of AI [22].

In addition to this, in study by Gado et al. [22] developed and tested a new model to explain what factors are relevant to predict psychology students' attitude towards AI and their intention to use it. The study found that perceived usefulness, perceived social norm, and attitude towards AI were significant predictors of intention to use AI. Perceived knowledge of AI was also a significant predictor of intention to use AI, especially for female participants. The study suggests that psychology training programs should focus on fostering a positive attitude towards AI among students by emphasizing its usefulness and ease of use in psychologists' work contexts. Additionally, programs should help students to develop the knowledge and skills they need to use AI effectively.

Another example is the article "Training the next generation of counselling psychologists in the practice of telepsychology" discusses the need for training programs to prepare counseling psychologists for the future of service delivery in psychology, which increasingly includes the use of telepsychology. The authors note that there are few options available for trainees seeking to acquire experience in

telepsychology and that guidelines for training programs in this area are virtually non-existent [23].

However, in a study organized by Perle et al. [24], researchers surveyed 782 psychological and medical professionals about their interest in videoconferencing telehealth training and mental health telehealth referral. Results showed that both groups were interested in telehealth training, with psychological professionals more likely to be interested. The most desired training topics were efficacy data, ethical issues, and legal concerns.

Developing comprehensive university standards for online crisis counselling is vital to preparing students for the dynamic demands of this field. Key components and considerations include curriculum design:

1) core courses: cover fundamental topics such as technology integration, ethics, and cutting-edge innovations (figure 2);
2) elective courses: allow specialization in areas like teletherapy, digital interventions, data analytics, or app development.

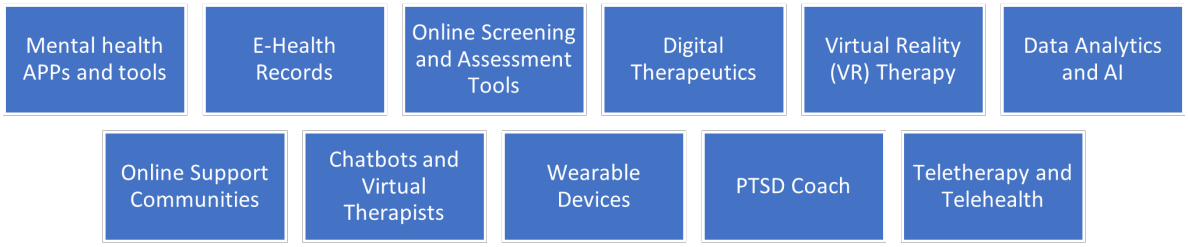


Figure 2: Fundamental topics of mental health technologies for online crisis counselling university courses.

That is why, the online crisis counselling course should adopt an interdisciplinary approach, encouraging cooperation between psychology, computer science, data science, and public health departments to promote a comprehensive view. An integral component of the curriculum focused on ethical foundations, highlighting ethical principles such as safeguarding data privacy, ensuring informed voluntary consent, and the responsible usage of AI in diagnosis and treatment [13].

Additionally, the main attention in course development revolves around development proficiency in the evaluation and application of mental health technologies [25]. This includes the acquisition of required technological skills for evaluation and effective use of an array of mental health apps, including apps, wearables, telehealth platforms, and data analytics resources (figure 2).

First of all, the course should include the specifics of working with mental health apps [15] and digital therapeutics (DTx) [26], virtual reality (VR) Therapy [11] as tools for supporting clients (figure 3). A lot of mobile applications have been created to assist individuals in overseeing their mental well-being. These applications include functionalities like monitoring emotional states, meditation and mindfulness practices, use of cognitive-behavioural therapy (CBT) methods and fostering peer connections for support. It is quite important for psychology students to understand how to use these tools to support community mental health.

VR technology is increasingly used in exposure therapy for PTSD and phobias. It allows individuals to confront and manage their fears in a controlled and immersive environment. As described in the research by Usmani et al. [11], the future of mental health within the metaverse lies in the potential use of immersive digital realms, referred to as the metaverse, for solving mental health issues.

The course should also cover how to use telehealth and teletherapy to support clients specifically. Telehealth and teletherapy platforms have revolutionized the provision of therapeutic and consulting services, enabling individuals to access these vital services remotely through video calls, phone calls, or text messaging. For instance, Miu et al. [27] investigates the impact of the COVID-19 pandemic on psychotherapy, with a specific focus on individuals who have serious mental illness (SMI). These

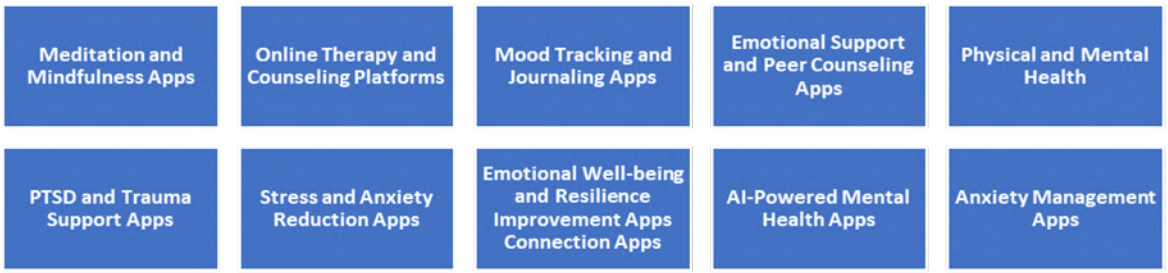


Figure 3: Mental health apps.

findings shed light on the viability and effectiveness of telehealth for individuals with serious mental illness amidst the challenges posed by COVID-19.

It is equally important that the course included the specifics of working with online screening and assessment tools [7, 11], wearable devices [28] as tools for client self-diagnosis. Certain wearable fitness trackers and smartwatches are already equipped with functions to monitor stress levels, sleep patterns, and physical activity [28].

Last but not least, data analytics and AI topics should be included in university courses. Advanced analytics and machine learning can help healthcare providers and researchers identify patterns and trends in mental health data. This can lead to more personalized treatment plans and a better understanding of mental health disorders.

While mental health tech is a valuable resource, it should complement, but not replace, professional mental health care. It can provide additional tools for managing mental well-being, but seeking guidance and treatment from trained professionals remains essential for severe or persistent issues. Traditionally, the online crisis counselling course has been perceived as challenging by students due to its reliance on statistical analysis tools and a complex process involving manual decoding of raw survey data, organizing the data, and defining variables using SPSS statistical packages or R coding. These tasks require additional software knowledge and programming skills, which psychology students often find challenging extracurricular tasks.

2.3. Student engagement and satisfaction of online learning

Student engagement and satisfaction are essential to successful online learning. The Zhang Scale of Transactional Distance (RSTD) is a valuable tool for educators to measure and address transactional distance, a key factor influencing student engagement and satisfaction in online online crisis counselling course [29]. Transactional distance refers to the psychological-pedagogical space that separates students from their peers, instructors, course content, and learning interface. This can be caused by various factors, such as:

1. Online students may feel isolated from their peers and professors, leading to decreased engagement and satisfaction [30].
2. Poorly designed or uninteresting online courses can lead to longer distances between transactions. Significant development and widespread adoption of artificial intelligence and no-code software in early 2023 are driving demands for the adoption of AI technologies in course design. Therefore, offering a module that integrates artificial intelligence into online crisis counselling course provides an exceptional opportunity to explore the sought-after convergence of technology and mental well-being. This interdisciplinary approach not only reflects the evolving landscape of mental health support but also gives students additional time to make informed decisions about the data [29, 30].
3. Students may experience technical difficulties accessing course content or using statistical packages purchased by the university, which may also increase the distance between transactions.

However, the developed public platforms are widely available and do not require a presence at the university [31].

RSTD quantifies transaction distance along four key dimensions [32]:

1. transactional distance between students (TDSS) (measures the perceived psychological and educational gap between students in an online learning environment);
2. transactional distance between student and instructor (TDST) (measures the perceived separation and interaction dynamics between students and their instructors in an online course);
3. transactional distance between learners and content (TDSC) (measures the perceived distance or cognitive space between learners and course content or materials);
4. transactional distance between learner and interface (TDSI) (measures the perceived distance between learners and the technology interface or platform used for learning).

In our case, we use RSTD to identify areas for improvement in an online course to evaluate the effectiveness of instructional interventions aimed at reducing transaction distance and increasing student engagement and satisfaction. Given the aforementioned prerequisites, the research inquiry will encompass the following: evaluate the transactional distance encountered by students and their satisfaction levels while utilizing an AI in online crisis counselling course and Data Analytics?

3. Methodology

This study aimed to assess the academic performance and satisfaction of psychology students in their study of the module "Mental Health Technology and AI" in the pilot course "Crisis Online Counselling", explicitly emphasizing the integration of artificial intelligence and machine learning. The research took place in an online format during the 2023-2024 academic year against the backdrop of the ongoing conflict in Ukraine. The research employed a mixed-methods approach to investigate the transactional distance experienced by students enrolled in the course.

3.1. Sampling and procedures

In total, 60 students (table 1) participated in the course. The participants included 80.5% females and 19.5% males. There was no significant difference in the distribution of participants into groups based on gender ($\chi^2(2) = .444, p = .79$). The average age of participants was $M = 20.3$ years ($SD = 2.4$). Most participants were preparing for careers as practical psychologists in educational institutions (53.1%), while the rest aimed to become private (46.9%) psychologists. These two conditions did not significantly differ regarding participants' educational paths ($\chi^2(1) = 1.793, p = .18$).

Table 1
Demographics of the present sample ($N = 60$, mean age = 20.5; $SD = 1.07$).

Variable	Type	Frequency
Gender	Male	12
	Female	48
Age categories	18–24 years old	58
Age categories	25–34 years old	2
Academic status Diploma	BA	60
Department	Psychology	44

Moodle served as the asynchronous platform, while Zoom facilitated synchronous learning and lab work presentations. This approach allowed for a comprehensive exploration of the research problem by combining both quantitative and qualitative data collection and analysis, shedding light on the dynamics of teaching and learning in the specific context of wartime.

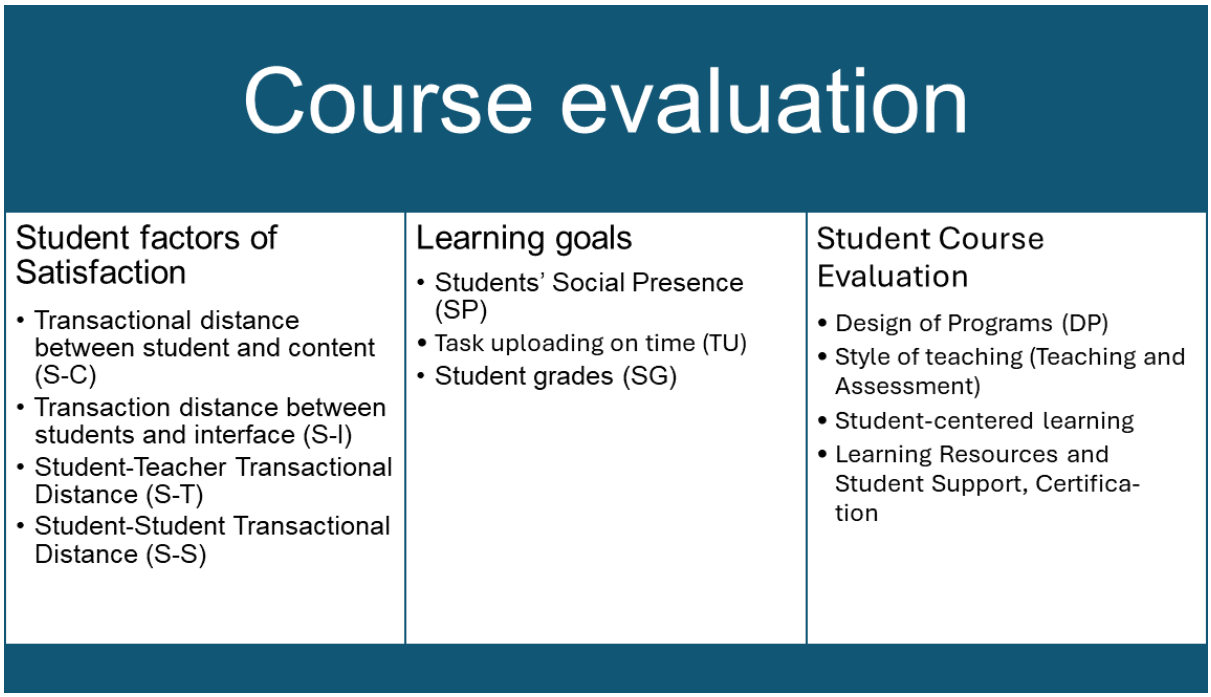


Figure 4: The research model of the study.

The procedure for our controlled experiment was conducted as part of the pilot module (1 ECTS) of an "online crisis counselling" course (3 ECTS). The study involved students studying for a BA degree in psychology at a pedagogical university.

Research on the use of student course evaluations has demonstrated a wide range of applications as quality indicators of the system, for enhancing the expansion of students' rights and opportunities, and as tools for measuring educational quality. Accordingly, this study hypothesized that course evaluation is associated with quality of content.

Based on previous research and the development of the model of evaluation, the following hypotheses were formulated, and the proposed research model is illustrated in figure 4.

Here's a breakdown of the procedure:

1. The entire module lasted a total of 4 weeks and consisted of four course topics. Each course topic, "Diagnostics of mental health in technology", "Exploratory Data Analysis (EDA)", "Setting up a chatbot model" and "Evaluation", lasted one week.
    - *The topic "Diagnostics of mental health in technology"* was aimed at studying the analysis of data on mental health for IT companies; we have selected a list of diagnostic tools to analyze the mental health, burnout and resilience of university IT stakeholders ("Mental Health Rating Scale", "Resilience Rating Scale"; individual and organizational stressors, internal and external, as well as 5 open-ended questions about energy demands at work and resilience practices, managerial encouragement, and types of company assistance during war). The SurveyMonkey platform was used to collect mental health data.
    - *The topic "Exploratory Data Analysis (EDA)"* was the data analysis task used several tools: ChatGPT or Bard to code Python commands for data preparation (including raw data cleaning, data quality assurance, anonymization and protection of confidential information for ethical reasons). Also, used Dataiku EDA tools for visual data exploration and descriptive statistics of a sample. The primary goal was to identify patterns, correlations, and potential anomalies in data on mental health, resilience, and stress levels among wartime IT professionals. Next, the goal was to find relevant characteristics or variables that could be useful for analyzing mental health, such as average stress levels, identifying periods of high stress, or classifying employees based on their mental health status.

- *The topic "Setting up a chatbot model"* included content and cluster analysis of open questions (setting up a chatbot model, specifying the context, querying a model with relevant questions, templates based on text data, on which GPT is trained) and skills in using Dataiku for machine learning without coding.
- *The topic "Evaluation"* explained the components of the report and the formulation of conclusions, problems associated with human verification and validation of models.

2. Presentation of course content: students attended lectures and two practical sessions conducted by the same teacher for all students.

3.2. Research design and setting

Research into the utilization of student course evaluations has unveiled a diverse array of applications, serving as barometers of system quality, tools for enhancing student empowerment, and metrics for assessing educational excellence. Consequently, this study posited an association between course evaluations and teaching quality.

Drawing upon prior research and the model, the ensuing hypotheses were formulated. The research model proposed in figure 4 encapsulates these research questions:

- **Research question 1.** How does the utilization of AI tools (AT) influence the factors contributing to student satisfaction in online learning (SfS)?
- **Research question 2.** What is the relationship between student factors of satisfaction in online learning (SfS) and their achievement of learning goals (SS)?

A web-based email surveys were designed for asynchronous data collection to gather feedback through the student evaluation of teaching (SET) [33] that includes Zhang's transactional distance scale and online survey proposed by the National Agency for Higher Education (Methodology of independent, external, on-site evaluation of the quality of legal education in Ukraine) (A and B).

1. The instruments evaluated both student satisfaction with the course and the perceived transactional distance between students and their instructor, as well as between students and course materials. To minimize potential biases, both Zhang's scale and the student satisfaction questionnaire utilized a Likert scale with five response options, ranging from "completely disagree" to "completely agree."
2. Respondents' perceptions regarding the quality of teaching are examined based on four indicators: teaching style, student-centered learning, learning resources and support, certification, and program design. The survey on teaching quality in universities under war conditions, conducted through computer-based Google Forms, comprised 20 questions and 4 statements regarding perceived course benefits, associated factors, and participant behavioral characteristics during the study process. Responses were scored on a 5-point Likert scale from "never true" to "almost always true," and each item was analyzed individually to provide specific insights into its content.
3. Following the completion of the course module, students underwent an online knowledge test. To pass the required knowledge test (Student's graduates) on the Moodle platform, students initially needed a minimum of 50% correct answers on the multiple-choice questions.

Data analysis will be analyzed using Jamovi. Descriptive statistics, including correlation analysis using the Pearson criterion, were used to quantitatively assess the relationship between academic achievement and the effectiveness of Online crisis counseling training, determining the strength and direction of this association. Quantitative data from the Zhang scale will undergo descriptive statistical analysis to uncover patterns and trends in students' perceptions of transactional distance [34]. Inferential statistical tests, correlation analysis, specifically employing the Pearson criterion, was used to determine the relationship between transactional distance scales, and the effectiveness of training quantitatively. This analysis aimed to establish the strength and direction of the association between these variables. [35].

4. Data analysis

The overall satisfaction with the course among participants was notably high, with an average rating of 4.37 and a standard deviation of 0.991, on a scale ranging from 1 to 5 (SS = Student satisfaction "Overall, I am satisfied with this course"). Particularly, students expressed a strong appreciation for the interaction facilitated by the AI tools utilized in the classes (SI = Transaction distance between students and interface, averaging 3.97 with a standard deviation of 0.68) (table 2).

Table 2
Indicators of the transaction distance of the sample ($N = 60$).

Scales	Mean	SE	SD
S-C	3.65	0.0884	0.685
S-I	3.97	0.0750	0.581
S-T	4.00	0.1258	0.974
S-S	4.32	0.1176	0.911
LG	3.93	0.1383	1.071
SS	4.37	0.1279	0.991

However, there was a perceived decrease in student ratings concerning the transactional distance between students and course content, with a mean rating of 3.65 and a standard deviation of 0.68. On the other hand, students rated their transactional distance with teachers and peers relatively high, with average values of 4.00 ($SD = 0.974$) and 4.32 ($SD = 0.911$), respectively (table 2).

Transactional distance is associated with a grade on most dimensions. Post hoc analysis revealed the most significant differences (table 3).

Based on our empirical analysis, we applied logical and statistical tests, particularly using the Pearson criterion for correlation analysis. We tested the quantitative relationships between:

1. Assessment of the quality of the knowledge obtained in the online test and the effectiveness of participation in the course.
2. The total number of timely submitted reports and their correlation with the quality assessment.

We used Pearson's correlation to illustrate these relationships, recognizing that the correlation coefficient may not reach a perfect. We also applied non-parametric significance tests to establish statistical significance due to the limited distribution information of in the data.

Table 3
Indicators of students' work systematicity on the basis of assignments ($N = 60$).

Assignment title	Number[a]	Correlation[b]	Grade satisfaction[c]
The topic "Diagnostics of mental health in technology"	41	–	0.68
The topic "Exploratory Data Analysis (EDA)"	36	0.67	0.56
The topic "Setting up a chatbot model"	49	0,45	0,62
The topic "Evaluation"	56	0,51	0,63

Note: [a] – number of reports that were uploaded in time; [b] – correlation with the grade for quality (online knowledge test); [c] – correlation with the grade for quality the total number of reports that were uploaded in time.

Based on the provided correlations (table 4), the factors can be ranked from powerful to less powerful associations and organized into groups :

Group 1: Moderately strong

1. Transactional distance between students and content (S-C) correlates positively with:
   - Students' social presence (SP) ($r = 0.61$)
   - Learning goals (LG) ($r = 0.43$)

Table 4
Course evaluation correlations ($N = 60$).

Scales	S-C	S-I	DP	LG	SG	SP
Transactional distance between student and content (S-C)	–	0.31	0.27	0.43	0.39	0.61
Transaction distance between students and interface (S-I)		–	0.33	0.38	0.56	0.36
Design of programs (DP)			–	0.52	0.44	-0.26
Learning goals (LG)				–	0.44	0.45
Student grades (SG)					–	0.56
Students' social presence (SP)						–

- Student grades (SG) ($r = 0.39$)
- Transactional distance between students and interface (S-I) ($r = 0.31$)
- Design of programs (DP) ($r = 0.27$)

2. Transactional distance between students and interface (S-I) correlates positively with:
   - Student grades (SG) ($r = 0.56$)
   - Learning goals (LG) ($r = 0.38$)
   - Design of programs (DP) ($r = 0.33$)

Group 2: Moderately strong relationships

4. Learning goals (LG) show positive correlations with:
   - Student grades (SG) ($r = 0.45$)
   - Students' social presence (SP) ($r = 0.45$)

Group 3: Moderately strong with weaker negative relationship

3. Design of programs (DP) correlates positively with:
   - Learning goals (LG) ($r = 0.52$)
   - Student grades (SG) ($r = 0.44$)
   - but negatively with:
   - Students' social presence (SP) ($r = -0.26$)
5. Student grades (SG) display a positive correlation with:
   - Students' social presence (SP) ($r = 0.56$)

This organization highlights the strengths of associations between different factors, categorizing them into groups based on their correlation values. Here are the definitions for each group based on the revised organization of factors:

Group 1: Strong correlations. This group highlights significant correlations between the transactional distance between students and content (S-C) and both students' social presence (SP) and learning goals (LG). These relationships of factors indicate robust connections, suggesting that when students feel engaged with course content, they are more likely to be socially present and focused on achieving learning objectives.

Group 2: Moderate correlations. Comprising moderate correlations, this group underscores the relationships between Student-Content and various other factors, including student grades (SG), transactional distance between students and interface (S-I), and design of programs (DP). While these relationships are not as strong as those in Group 1, they still suggest moderately strong links between different aspects of the course evaluation.

Group 3: Moderate correlations with a weaker negative relationship. Characterized by moderate associations with a weaker negative relationship, this group reveals the complex interplay between design of programs (DP), learning goals (LG), student grades (SG), and students' social presence (SP). Despite the presence of negative correlations, the overall associations within this group are moderate, indicating nuanced relationships among these factors.

This refined organization provides a comprehensive understanding of the varying strengths of associations among different factors in course evaluations, offering valuable insights for future research and course improvement initiatives.

5. Discussion

Study results highlight the effectiveness of training and the achievement of favorable educational outcomes in the context of integrating artificial intelligence and no-code machine learning for mental health data analysis. Not only does the popularity of discussing these tools ensure that students are involved in studying the subject, but also in conditions of forced online learning against the backdrop of war, it creates a reduction in the distance regarding the use of interfaces and software that does not require the use of programs purchased by the university and stay on campus.

- **Research question 1 aimed to investigate the influence of AI tools (AT) on factors contributing to student satisfaction in online learning (SfS).**

The study found that overall satisfaction with the course was high, with an average rating of 4.37 and a standard deviation of 0.991. Notably, students appreciated the interaction facilitated by AI tools, as indicated by a mean transaction distance between students and interface (SI) of 3.97 with a standard deviation of 0.68 (table 1). However, there was a perceived decrease in ratings for transactional distance between students and course content (S-C), with a mean rating of 3.65 and a standard deviation of 0.68. Conversely, transactional distance with teachers (S-T) and peers (S-S) was rated relatively high, with average values of 4.00 ($SD = 0.974$) and 4.32 ($SD = 0.911$), respectively.

In addition, the study highlights the specific satisfaction of students using learning analytics tools integrated with artificial intelligence. The main objective of the module was to provide psychology students with fundamental competencies to analyze mental health data and solve problems relevant to the ongoing conflict in Ukraine. However, it is critical to understand both the general and specific trends identified in the data set.

Transactional satisfaction distance has also demonstrated a correlation with measures of successful task completion within a given time frame. According to our previous research [33], students who had difficulty meeting assignment deadlines tended to perceive greater transactional distance when interacting with both the course interface and course content, particularly the topic of data ethics. However, their interaction with peers during group assignments remained minimal.

The student research team's primary goal was to identify patterns, correlations, and potential anomalies in a data set related to mental health, resilience, and stress among wartime IT professionals. Deploying trained models into Dataiku enabled real-time predictive analysis. Notably, among students classified as absent, a key factor influencing assignment quality was the presence or absence of strong educational goals. These results are close to the conclusions of research on student motivation [36].

Emphasis during the practicum was on the ethical handling of sensitive mental health data and adherence to confidentiality protocols. However, open-ended responses indicated that students had difficulty completing assignments within the time limits and were only able to engage superficially with ethical considerations. It's close to the results of research [37], where Moodle was found to be ineffective and 92.4% of students considered it a time-wasting tool. Notably, in our research as well as research by Best there were no strong contrary opinions; most respondents were neutral [37].

- **Research question 2 investigated the relationship between student factors of satisfaction in online learning (SfS) and their achievement of learning goals (SS).**

The study found that students with higher grades, such as those in the "B" category, primarily focused on reducing transactional distance related to content, interface, and peer interactions. Conversely, students with lower grades, specifically those in the "C" category, reported dissatisfaction and concentrated efforts on reducing transactional distance associated with content, interface, and teacher parameters.

Based on the provided correlations (table 4), the factors were organized into groups based on their correlation values. In Group 1, characterized by moderately strong associations, transactional distance between students and content (S-C) showed positive correlations with students' social presence (SP), learning goals (LG), student grades (SG), transactional distance between students and interface (S-I), and design of programs (DP). Group 2 highlighted moderately strong relationships, with learning goals (LG) positively correlating with both student grades (SG) and students' social presence (SP). Group 3, displaying moderately strong associations with a weaker negative relationship, revealed that the design of programs (DP) correlated positively with learning goals (LG) and student grades (SG) but negatively with students' social presence (SP). Additionally, student grades (SG) in Group 3 displayed a positive correlation with students' social presence (SP).

This organization provides valuable insights into the strengths of associations between different factors, allowing for a clearer understanding of their relationship with student satisfaction and achievement of learning goals in online learning environments.

6. Conclusion

This research explores the potential of AI to improve mental health education and data analysis learning, demonstrating the significant benefits it can bring to individuals and organizations. As technology advances, the synergy between human intelligence and artificial intelligence will play a key role in shaping the future of work and well-being. The results of this study provide information about the influence of relevance of course content on student perception.

The hypothesis, that the declining transactional distance between student-content and interface correlates with their grade (academic performance) while utilizing an AI in Mental Health Tech and Data Analytics, was supported. This finding suggests that active participation in the course, coupled with understanding how artificial intelligence tools can be applied in a psychological context, can positively influence students' career intentions. This emphasizes the role of practical experience and practical application in shaping students' professional trajectories.

Conducting this study in an online format during the conflict in Ukraine adds a unique dimension to the research. This reflects the adaptability and resilience of students and teachers in the face of difficult circumstances. The findings emphasize that even under these conditions, effective teaching strategies can make a significant difference in students' learning experiences and outcomes.

7. Significance and consequences

The research is particularly noteworthy for several reasons. For educators, this highlights the value of incorporating real-world relevance into curriculum development and providing students with opportunities to work with emerging technologies. Conducted during the 2022-2023 academic year amidst the ongoing conflict in Ukraine, this study navigates the unique challenges presented by the online format. This context adds relevance and urgency to understanding student engagement and achievement in such conditions. The study addresses the complexity associated with the subject matter, which students often consider challenging. This complexity stems from the reliance on statistical analysis tools and the need for skills in decoding raw data, data organization, and using statistical packages. Investigating how students cope with these demands is of substantial significance. By examining how students perceive the relevance of course content and their intentions to apply artificial intelligence tools in their future careers, this research sheds light on the effectiveness of educational approaches in preparing students for the evolving demands of their field.

8. Ethical considerations

Students were assured anonymity and that survey responses wouldn't affect their course assessment. Before the survey, participants consented to data use, including knowledge test scores. Two months post-data collection, participants received a thorough debrief with initial findings. This process ensured ethical and systematic experiment execution in the university course context.

Funding: Project ERASMUS-EDU-2023-CBHE101129379 "Boosting University Psychological Resilience and Wellbeing in (Post-) War Ukrainian Nation".

Declaration on Generative AI: During the preparation of this work, the author) used GPT-4o in order to: Improve writing style, Content enhancement. After using this tool, the author(s) reviewed and edited the content as needed and takes full responsibility for the publication's content.

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A. Student course evaluation "Survey on the quality of teaching disciplines"

Instruction: *"Dear Student! The University Administration invites you to take part in a survey on the level and quality of teaching disciplines. Your answers will help to improve the educational process and improve the quality of education at the university. The survey is conducted anonymously. Thank you in advance for participating in the survey!"*

Zhang's scale of transactional distance

ST = Transactional distance between students and teacher

1. The instructor generally answers the student's questions
2. The instructor pays no attention to me
3. I receive prompt feedback from the instructor on my academic performance
4. The instructor was helpful to me
5. The instructors are available to answer my questions
6. The instructor can be turned to when I need help in the course

SC = Transactional distance between student and content

7. The content of this course is of great interest to me
8. I don't know why I have to learn this
9. The examinations in this course have challenged me to do my best work
10. This course emphasized SYNTHESIZING and organizing ideas, information, or experiences into new, more complex interpretations and relationships
11. This course emphasized MAKING JUDGEMENTS about the value of information, arguments, or methods such as examining how others gathered and incorporated data and assessing the soundness of their conclusions
12. This course emphasized APPLYING theories and concepts to practical problems or in new situations

SS = Transactional distance between students and students

13. I learned a lot from observing the interactions among the students
14. The students in this online class challenged me to do my best work
15. I get along well with my classmates
16. I feel valued by the class members in this online class
17. My classmates in this online class value my ideas and opinions very highly
18. My classmates respect me in this online class
19. I am good at working with the other students in this online class
20. I feel a sense of kindred spirit with my fellow classmates
21. The class members can be turned to when I need help in the course
22. There are students I can turn to in this online class
23. The class members are supportive of my ability to make my own decisions

SI = Transactional distance between students and interface

24. It is difficult to pay attention to the instructor in the web environment
25. I have adequate access to the web resources I need
26. The fact that I am online does not inhibit my class participation
27. An efficient system is provided for students and instructors to exchange materials
28. I am comfortable using the computer
29. I hate using the web
30. It was easy for me to use the technology involved with this online class
31. The technology used in this course is difficult to learn and use

SL = Student learning

I have learned a great deal in this online class
LG = Learning goals
I have made tremendous progress towards my goal in the subject area of this course
SS = Student satisfaction
Overall, I am satisfied with this course
Please give 3 recommendations to improve course design

B. Student course evaluation "Survey on the quality of teaching disciplines"

Instruction: *"Dear Student! The University Administration invites you to take part in a survey on the level and quality of teaching disciplines. Your answers will help to improve the educational process and improve the quality of education at the university. The survey is conducted anonymously. Thank you in advance for participating in the survey!"*

20 questions on a 5-point scale, 3 questions with answer options, and 1 open-ended question. For all psychological variables, respondents gave answers on a 5-point Likert scale from "(1) never true" to "(5) almost always true" in Google Forms.

Design of programs:

1.1. I need discipline for my future professional activity.
1.2. The discipline contains useful material.
1.3. The discipline is logically connected with other disciplines.
1.4. The discipline contributes to the formation of skills and abilities.
1.20. In general, it was interesting for me to master this discipline.

Style of teaching (teaching and assessment):

1.6. The professor is fluent in educational material and modern scientific information;
1.7. The professor motivates students to independently search for information in depth;
1.8. The professor clearly formulates the goals and the training plan;
1.9. The educational material is presented in an accessible and interesting way;
1.10. The professor uses the latest interactive teaching methods.

Student-centered learning:

1.12. I have the desire to continue studying with this teacher (other disciplines, coursework, qualification work);
1.13. The teacher is open and friendly with students;
1.14. I always had the opportunity to turn to the teacher for clarification or advice;
1.16. The teacher is tactful and knows how to establish contact with students.

Learning resources and student support, certification:

1.5. The discipline is provided with the necessary textbooks and teaching materials.
1.11. The teacher clearly defines the criteria for assessing students' knowledge.
1.17. The professor always conducts classes on time and according to the schedule.
1.18. Distance learning was well organized by the professor.
1.19. But, in my opinion, it would be more correct to teach the discipline personally.

The role of educational and scientific studies taxonomies in a centralised informational web-oriented educational environment

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Abstract

Scientific and educational studies can be structured using the formalisation of the IMRAD approach, providing data interoperability. This study focuses on using study results as part of a centralised informational web-oriented educational environment. Structurisation was applied to two studies: "Development of a rational approach for utilising methane tank waste at LLC Vasylkivska chicken farm" and "Development of a strategy for utilising methane tank effluent". Specific tools from CIT Polyhedron were used to process study data. The audit tool compares newly inputted data to existing taxonomies and highlights cases of full correspondence between elements of different works, such as study objects. The approach of integrating studies with educational ontologies, which is part of the centralised informational web-oriented educational environment, is described. The formalisation of this process is described using mathematical expressions.

Keywords

ontology, educational research, scientific studies, taxonomy, centralised educational environment

1. Introduction

Science now affects all aspects of human life more than ever before. The latest scientific developments are often quickly implemented in industry. However, scientific results are usually presented in human-readable form rather than machine-readable format, making it difficult to process the knowledge using automated informational technologies.

The basic structure of a typical research paper is the sequence of Introduction, Methods, Results, and Discussion (sometimes abbreviated as IMRAD) [1]. Each section addresses a different objective. The Introduction motivates the research problem or known facts about it; the Method section states what the authors did to learn about and address the issue with a new solution, what they achieved in experiments is described in the Discussion section, and their observations are discussed in the Results section.

The most common form of scientific reporting is a written paper. Depending on the purpose, there are several different paper types: Analytical Research Paper, Argumentative (Persuasive) Research Paper, Definition Paper, Compare and Contrast Paper, Cause and Effect Paper, and Interpretative Paper. The most common research paper types are shown in table 1 [2].

Nowadays, most papers (but not all) are systematised using scientometric databases. However, educational research reports, which use scientific methods, have not been systematised. Unlike pupils, scientists already know their field of research in detail and can determine their research hypothesis, and they can do further analysis by themselves. Students, instead, cannot do this. Automated informational tools can help students in these scientific discovery and analysis tasks.

AREdu 2024: 7th International Workshop on Augmented Reality in Education, May 14, 2024, Kryvyi Rih, Ukraine
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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

CEUR-WS.org/Vol-3918/paper022.pdf

Table 1
The most common research paper types.

Types of the research papers	Oriented amount of words required	Specific characteristics
Analytical Research Paper	3000+	Someone poses a question and then collects relevant data from other researchers to analyse their different viewpoints.
Argumentative (Persuasive) Research Paper	3000+	The argumentative paper presents two sides of a controversial question in one paper.
Definition Paper	5000+	The definition paper describes facts or objective arguments without using any personal emotion or opinion of the author.
Compare and Contrast Paper	5000+	Compare and contrast papers are used to analyse the difference between two viewpoints, authors, subjects or stories.
Cause and Effect Paper	3000+	Cause and Effect Paper traces probable or expected results from a specific action and answers the main questions "Why?" and "What?".
Interpretative Paper	3000+*	An interpretative paper requires one to use knowledge gained from a particular case study.
Experimental Research Paper	3000+*	This type of research paper describes a particular experiment in detail.
Survey Research Paper	5000+*	This research paper demands the conduction of a survey that includes asking questions to respondents.

* Depends on the purpose of the article and the requirements of the journal, institute, teacher.

The STEM (Science, Technology, Engineering and Mathematics) approach may be interpreted as using the scientific method in an educational process while providing academic research. This approach has only recently been applied in countries such as Ukraine. There are various school competitions for scientific works, such as the competition on scientific articles of the Junior Academy of Sciences of Ukraine and international competitions (Intel ISEF). Also, the scientific method can be used during the creation of thesis papers (for masters' degrees, bachelor's degrees, etc.) and pupils' research reports (for events noted before), or in simpler, but more common form of essays. In addition, students can report their results in scientific papers if the quality of their work meets scientific requirements. An overview of the types of educational research reports is presented in table 2. This paper focuses on the systematisation and processing of academic research reports. The problem to be addressed is the lack of a structuring mechanism that complicates the automated processing of such reports.

Table 2
Types of educational research reports.

Types of the educational research report	Oriented required amount of the pages	Specific characteristics	The event for which the report was prepared
Essay	In general, up to 10-15 pages	Simple and very flexible in content	Classes, school-level competitions
Research reports	In general, up to 30-100 pages	Relatively static structure; similar to IMRAD	Competitions of Junior Academy of Sciences of Ukraine and Intel ISEF
Scientific paper	Declared by the source	Declared by the source	Publication in a journal
Thesis papers	In general, 40-100 pages	Relatively static structure similar to IMRAD	Defence of qualification works

2. Literature review

The active dissemination and use of different scientometric databases continue to increase the convenience and efficiency of scientific data processing, structuring, and systematisation of research and scientific results. Specialised databases for structural science information are an integral part of the information-support system for any scientist. Scientometrics is the "quantitative study of science, communication in science, and science policy" [3], commonly referred to as the "science of science". Scientometrics is essential to help academic disciplines understand various aspects of their research efforts, including (but not limited to) the productivity of their scholars [3, 4], the emergence of specialisations [5], collaborative networks [6], patterns of scientific communications [7], and quality of research products [8]. Metric studies have been developed as a subsidiary branch of Library and Information Science (LIS) [9]. Often, scientometrics applies bibliometrics, which measures the impact of publications.

To increase the quality and performance of scientometrics, the ten principles of the "Leiden Manifesto for Scientometrics" [9] have been stated:

1. Quantitative evaluation should support qualitative expert assessment.
2. Measure performance against the research missions of the institution, group, or researcher.
3. Protect excellence in locally relevant research.
4. Keep data collection and analytical processes open, transparent and simple.
5. Allow those evaluated to verify data and analysis.
6. Account for variation by field in publication and citation practices.
7. Base assessment of individual researchers on a qualitative judgement of their portfolio.
8. Avoid misplaced concreteness and false precision.
9. Recognise the systemic effects of assessment and indicators.
10. Scrutinise indicators regularly and update them.

Today, all existing scientometric databases can be divided into two major groups: international and national [9, 10, 11, 12, 13, 14, 15]. The most well-known international databases are Springer, Scopus, Web of Science, CiteseerX, Microsoft Academic, AMiner, Refseek, BASE (Bielefeld Academic Search Engine), WorldWideScience, JURN, Google Scholar, Google Patents, and others. National databases incorporate a variety of bibliographic databases and a variety of library and university repositories. International scientometric databases are characterised by a larger scale and mandatory support for various languages, including English. Also, a characteristic feature of such databases is the availability and work with multiple unique indices that have international recognition, for example, the h-index [16].

As scientific publications continue to grow exponentially, the number of academic databases and scientometric databases increases, which supports gaining insights into the structure and processes of science [14]. In this case, many scientific publications are devoted to the working principles of scientometric databases, and their number is growing. Thanks to them, concepts such as "metadata" of scientific articles began to be actively used in scientometrics [9, 10, 11, 12, 13, 14, 15]. Metadata is essential data about data providing information such as titles, authors, abstracts, keywords, cited references, sources, bibliography, and other data. Metadata does not substitute the corresponding article, but it explicitly describes valuable information about the report.

By using scientometric systems, researchers' contributions in informatics and scientometrics were previously quantified [11]. The principal metadata indicators are:

- The indicators and citation indices of journals.
- The number of authors.
- The number of publications.
- The degree of cooperation based on affiliation data.

The disadvantage of this research is that it is devoted only to scientific articles. The authors noted that their study could not cover students' and pupils' research reports because there is no single database where they are all located.

The application of the principles of the "Leiden Manifesto for Scientometrics" is stated and substantiated, providing transparent monitoring and support of research and encouraging constructive dialogue between the scientific community and the public. In this work, the bibliometric base, which corresponds to principles of the "Leiden Manifesto of Scientometrics", has been created. The proposed bibliometric center did not address the systematisation of students' and pupils' research reports. Still, the authors noted the necessity of involvement of students' and pupils' research reports in their bibliometric center.

The approach of co-word analysis has been introduced, and its application in scientometrics is substantiated in [12]. The trends and patterns of scientometrics in journals have been revealed by measuring the association strength of selected keywords which represent the produced concept and idea in the field of scientometrics. Also, the authors have developed a web system for extraction of keywords from the title and abstract of the article manually. However, the web system proposed by them cannot work with research reports of students and pupils.

Another concept of analysis is iMetrics, or "information metrics". Its application in scientometrics is substantiated in [17]. iMetrics is devoted to the scientometrics of scientific journals in the field of informatics. The authors note the possibility of applying their approach to the systematisation of the scientific works of students and pupils. The research related to scientometric databases is shown in table 3.

Table 3
Research related to scientometric databases.

Subject of study	The general result of the authors' study
Citation indices of journals, number of authors of the publication their affiliation	The contributions of researchers in the field of informatics and scientometrics [11]
Principles of the "Leiden Manifesto for Scientometrics"	Stated and substantiated "Leiden Manifesto for Scientometrics" [10]
Co-word analysis	The trends and patterns of scientometrics in the journals were revealed [12]
iMetrics ("information metrics")	iMetrics scientometric system has been provided [17]

Previously, ontological graphs were used to systematise scientific articles [18, 19, 20, 21]. Systematisation and structuring in such graphs are based on different approaches, such as using a scientific article recommendation system [18], Scientific Articles Tagging system [19], machine learning [20], and automatic summarisation [21]. Also, ontologies can be used to provide interoperability through semantic technologies [22]. However, none of the proposed ontological approaches for systematisation and structuring addresses the structuring of research reports of students and pupils.

None of the scientometric database systems previously proposed [9, 10, 11, 12, 13, 14, 15] can offer a universal solution for systematisation and structured presentation of research and scientific results to pupils and students. Also, the disadvantages of all these systems are the complete lack of many valuable parameters for processing information about scientific works. These parameters are the scientific novelty of the article, the practical value of the study, the hypothesis of the study, subject and object of the research. Also, existing solutions do not allow for comparing the metadata about the research reports between each other.

This work aims to propose and justify using an ontological system, which permits the systematisation of scientific articles with all advantages of existing scientometric systems and without disadvantages of these systems, which at the same time will not be deprived of the functionality of current scientometric systems and will meet the Leiden Manifesto for Scientometrics.

As Proof of Concept (PoC), we propose to use the existing cognitive IT platform Polyhedron as the technical basis for solving this problem. The core of the Polyhedron system consists of advanced and improved functions of the TODOS IT platform described in previous works. The Polyhedron is a multi-agent system that allows for transdisciplinarity and acts as an interactive component in educational and scientific research [23]. Besides, the cognitive IT platform Polyhedron contains a function for comparison with standards which is called auditing [23, 24, 25]. Polyhedron provides: semantic web support, information systematisation and ranking [26], transdisciplinary support, and

internal search [27], has all advantages of ontological interface tools [28], and the construction of all chains of the process of transdisciplinary integrated interaction is ensured [29]. Due to active states for hyper-ratio plural partial ordering [30, 31], the cognitive IT platform Polyhedron is an innovative IT technology for ontological management of knowledge and information resources, regardless of the standards of their creation. The user of the Polyhedron IT system has an opportunity to use an internal search function that has more views than the external one because it provides information created by experts.

Also, the proposed solution for the structuring of educational and research projects can be used together with other modern developments in the academic field, like a virtual educational experiment [32], different tools to provide development of ICT [33], the use of mobile Internet devices [34], using the technology of augmented reality education [35], online courses [36], distance learning in vocational education and training institutions [34], educational and scientific environments [27].

As was investigated before, the main elements of educational studies are represented by IMRAD nodes and their specific subnodes related to a particular study [37]. They may be described by a set of formulas. According to the theory of using IMRAD, each examination consists of an Introduction, Methods, Results, and Discussion (in terms of informational systems, the discussion is charged to processing – P):

$$\{I, M, R, P\} \in S \tag{1}$$

where I – node of ontology that integrates data related to introduction; M – subject of study: node of ontology that integrates data related to methods; R – node of ontology that integrates data related to results; P – results of study's results processing.

Each scientific study contains specific data structured by IMRAD, and it may be represented as a set of tuples (corteges) that describe elements of specific studies. The equations 2 and 3 are used to describe representing two different studies structured by IMRAD:

$$S_I = <I_I, M_I, R_I, P_I> \tag{2}$$

$$S_{II} = <I_{II}, M_{II}, R_{II}, P_{II}> \tag{3}$$

Two different studies integrated into a single ontology will be described as the sum of IMRAD elements. Such representation is shown in equation 4:

$$\langle S_I, S_{II} \rangle = \langle I_I, M_I, R_I, P_I, I_{II}, M_{II}, R_{II}, P_{II} \rangle \tag{4}$$

In such case, some specific elements of studies are overlapping and other are not. For example, the Method section of two different studies represented in form of an ontology using IMRAD will be as follows:

$$M_I = M_a, M_b, M_c, M_d \tag{5}$$

$$M_{II} = M_b, M_d, M_f \tag{6}$$

In such representation M_b and M_d belong to both studies, and it is possible to use them as linking nodes to connect the two studies:

$$M_b \in M_I, M_{II} \tag{7}$$

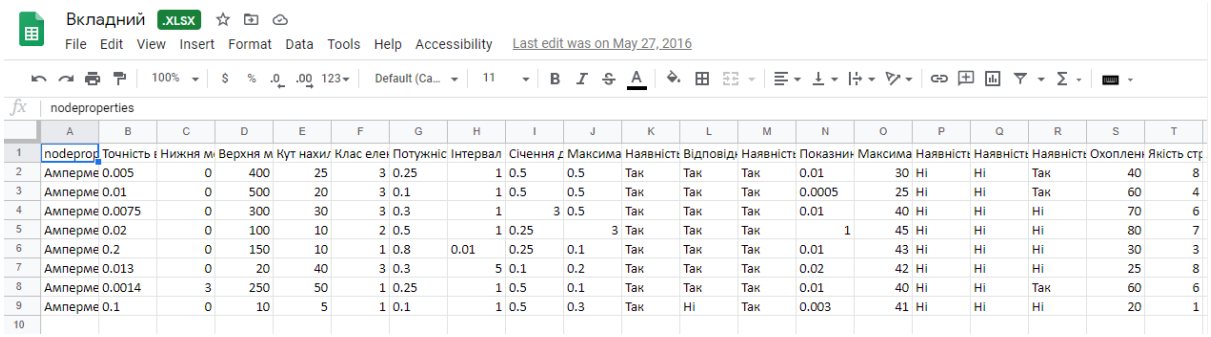
$$M_d \in M_I, M_{II} \tag{8}$$

It is worth noting that such representation of studies leads to the ontologisation of the studies' data. The most specific terms may be used to connect to different types of ontology-based knowledge, for example, educational programmes. However, such an approach was not conducted before. This study also aims to provide interoperability between different ontology-based knowledge systems using terms used in conducted studies and other knowledge systems (on the example of educational systems).

3. Materials and methods

3.1. Ontology creation mechanism

To create ontologies in Polyhedron, Google Sheets were used to collect and structure the information by an expert who took the data manually (see example in figure 1). The sheets with research report data (structure file and numeric/semantic data file) have been downloaded and saved in .xls format. The files have been loaded to "editor.stemua.science", part of Polyhedron. After that, the generation of the graph nodes (in .xls) with their characteristics using the data structures in the file has been carried out. The obtained graphs have been saved in .xml format and located in the database. The graphs have been filled with semantic and numeric information for ranking and filtering. Ontological edges (relations) have been formed using predicate equations, as described previously in [29].



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nodeproperties

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	nodeprop	Точність	Нижня м	Верхня м	Кут нахи	Клас еле	Потужніс	Інтервал	Січення д	Максима	Наявність	Відповід	Наявність	Показник	Максима	Наявність	Наявність	Наявність	Охоплені	Якість стр
2	Амперме	0.005	0	400	25	3	0.25	1	0.5	0.5	Так	Так	Так	0.01	30	Hi	Hi	Так	40	8
3	Амперме	0.01	0	500	20	3	0.1	1	0.5	0.5	Так	Так	Так	0.0005	25	Hi	Hi	Так	60	4
4	Амперме	0.0075	0	300	30	3	0.3	1	3	0.5	Так	Так	Так	0.01	40	Hi	Hi	Hi	70	6
5	Амперме	0.02	0	100	10	2	0.5	1	0.25	3	Так	Так	Так	1	45	Hi	Hi	Hi	80	7
6	Амперме	0.2	0	150	10	1	0.8	0.01	0.25	0.1	Так	Так	Так	0.01	43	Hi	Hi	Hi	30	3
7	Амперме	0.013	0	20	40	3	0.3	5	0.1	0.2	Так	Так	Так	0.02	42	Hi	Hi	Hi	25	8
8	Амперме	0.0014	3	250	50	1	0.25	1	0.5	0.1	Так	Так	Так	0.01	40	Hi	Hi	Так	60	6
9	Амперме	0.1	0	10	5	1	0.1	1	0.5	0.3	Так	Hi	Так	0.003	41	Hi	Hi	Hi	20	1
10																				

Figure 1: Google sheet with data.

3.2. Ranking tools

Considering that, e.g., proposed reports "A" and "B" are technical, the results of the reported works can be used to analyse the rationality of the implementation proposed in the concrete project. For instance, to offer it, research reports "A" and "B" were also compared with each other using a ranking tool applying the following criteria: "Short-term economic perspective", "Long-term economic prospects". For creating a ranking, the ontologies have used the module "Alternative", described in [26]. The nodes of a graph have been filled with semantic data to provide this ranking.

The ranking uses a grade scale from one to ten points to underline the relevance coefficient. The projects with a payback period of more than 25 years have been evaluated with 1 point, with 20-25 years of payback period with 2 points, from 15-20 years of payback period with 3 points, from 10-15 years of payback period with 4 points, 6-10 years of payback period with 5 points and with 1-5 years were evaluated as 6-10 points, respectively, by the "Economic attractiveness" criterion. A detailed evaluation for projects with 1-5 years is provided due to its utmost interest for the investor's "payback time", which determines investment expediency.

3.3. Auditing tools

To provide an audit of the hypothesis of work "A" and "B", the "standard" graph (with which the comparison is done) and the "comparison" graph (which is compared with the "standard") have been created. The "standard" ontology graph contains the data on hypotheses, subjects, objects of research, keywords, and other parameters of the research reports done before. For the "standard" graph, each parameter was presented in a separate node. The content of this ontological graph "standard" is constantly updated and supplemented.

The nodes of the "comparison" graph have been represented as names of the works which need to be audited with the "standard" graph. The parameters of the work used to be audited with the "standard"

graph have been located in the metadata of each separate node. The metadata type names were identical to the terms of the nodes of the "standard" graph to enable interaction between graphs.

3.4. Using centralised informational web-oriented educational environment concept and ensuring interdisciplinarity

The developed ontologies were saved in the same environment where elements of the centralised informational web-oriented educational environment were saved. Its features were used to provide interoperability with educational programs, methods, equipment, ontology-based didactical materials, and other ontology tools. As all such ontologies had the same graphs' nodes names, we provided the integration between elements of the centralised informational web-oriented educational environment and proposed structurisation of academic studies. We used the same nodes and provided links with each graph that it contains. For example, the term temperature regime that is used in educational programmes is connected with all academic programmes in physics (part of topic energy, thermal energy), chemistry (amount of topic energy of reaction), and scientific study graph that was conducted by a young researcher on biogas production research called temperature regime. Also, we can link this term with a method called ensuring of requested temperature by a thermostat and with equipment dry air thermostat. So, for this, we are using the term temperature regime to provide an interdisciplinarity approach that is related to different fields of science and to varying types of data (educational plans, equipment that is used, specific methods and specific personal studies).

4. Results and discussion

The general concept of the proposed ontology-based graph model for Polyhedron research reports has a specific, logically connected structure and can be represented as an ontology. After structuring, it is possible to describe the reports' content in a simpler to understand presentation form. Besides, most results can be domain-specific for each industry, and if the current standards are correctly identified, these values will be easy to compare. Also, most research in one field often uses the same equipment, materials, chemicals, standard methods of analysis, literature, etc., which allow comparing these works with each other and correctly structuring them.

However, the main advantage of the proposed approach (besides structuring the research) is processing results in terms of separated result parameters of the reports. This supports data analysis, further processing using ranking, and semantic data interoperability. The separation of numeric data and its location metadata class is possible due to the addresses of the same field, describing the process using the same (or similar) parameters of the process description and result parameters description. For example, for most reports on anaerobic digestion, the process parameters are temperature, type of substrate, reactor volume, moisture content, initial pH; the characteristics of efficiency of the process are biogas yield, methane content, average pH during the process, destruction process, etc. [38].

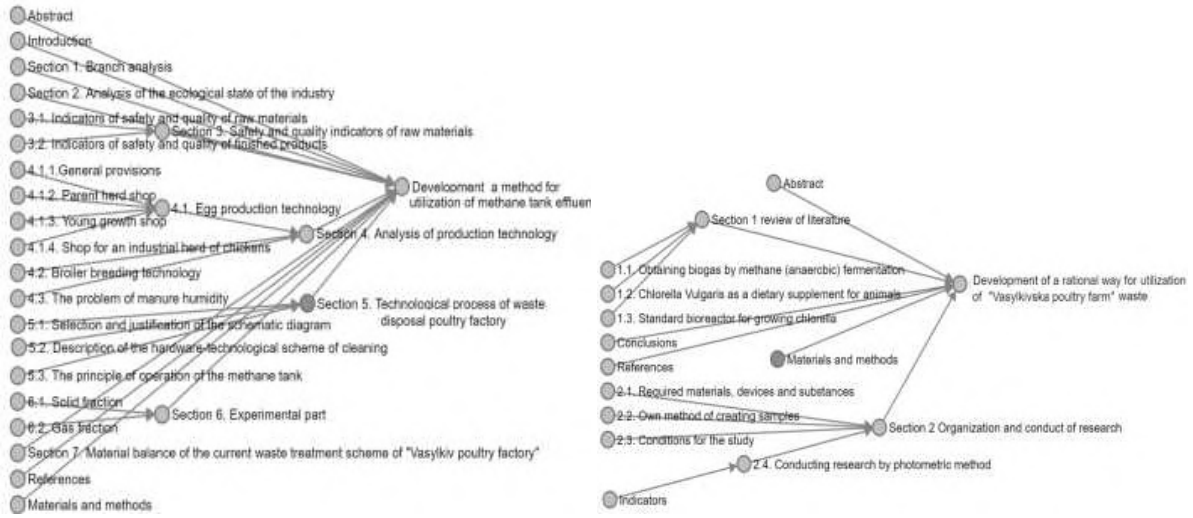
As all research reports will be simplified, this approach will be especially relevant for pupils and novice researchers with further potential use in the educational process or to streamline the literature review process for new academic research.

4.1. Description of scientific works used to provide structuring

For example, the object of the study of research report "A" is the disposal of anaerobic effluent. The subject of the report's research is the Cultivation of Chlorella Vulgaris microalgae on effluent obtained after methane fermentation. The study aims to develop a method of growing Chlorella Vulgaris in the effluent after methane fermentation. The practical significance of this scientific work is the results, which will contribute to the spread of biogas technologies. Also, the proposed approach makes it possible to increase the economic benefits of utilising chicken manure by converting the anaerobic digestion effluent into microalgae with a wide range of applications. The scientific novelty of that research report is a method of utilisation of anaerobic digestion effluent by using microalgae, also

had obtained cultures of Chlorella Vulgaris that had adapted to the anaerobic digestion effluent. The working hypothesis was that the effluent obtained after anaerobic digestion could be used as a nutrient medium for microalgae Chlorella Vulgaris.

The object of the research report "B" study is the disposal of anaerobic digestion effluent. The subject of the research is the processing of anaerobic digestion effluent into humates by the autocatalytic catalysis method. The study aims to establish regularities of processing the solid fraction obtained during the methane fermentation of chicken manure by the autocatalytic catalysis method. The practical significance of this scientific work is that the study indicates the possibility of acquiring salts of humic and fulvic acids by the autocatalytic catalysis method. This approach makes it possible to increase the economic benefits of chicken manure disposal by converting the anaerobic digestion effluent into a more valuable product with a wide range of applications. Its scientific novelty is that potassium humate had firstly obtained from anaerobic digestion effluent. For the first time, the efficiency of receiving humates from the solid fraction of anaerobic digestion was investigated, and the main regularities of the process were determined. The working hypothesis was that the solid fraction of methane fermentation of chicken manure can be recycled by the autocatalytic catalysis method.



(a) (b)

Figure 2: The general view of the (a) research report "A" (b) research report "B" ontological graph.

For both research reports, "A" and "B", chicken manure from the same poultry farm has been used as a substrate for anaerobic digestion. In this case, chicken manure and its effluent, which has been obtained by anaerobic digestion, were analysed by the same methods and indicators. Such indicators were:

- "Ash and dry content".
- "Determination of volatile fatty acids content" (in terms of acetic acid).
- "Determination of ammonium nitrogen content with Nessler's reagent".

The equipment used to determine these indicators was also the same. Therefore, how these works can be structured and integrated using the cognitive IT platform Polyhedron has been considered. All examples of ontological nodes in the obtained graphs for further potential information processing are presented in Table 4.

4.2. Structuring of the scientific works using ontologies

To present possibilities and systematisation of the research report, we have applied an ontological taxonomy for students' works "A" and "B". The general view of the obtained graphs is shown in figure 3 [29].

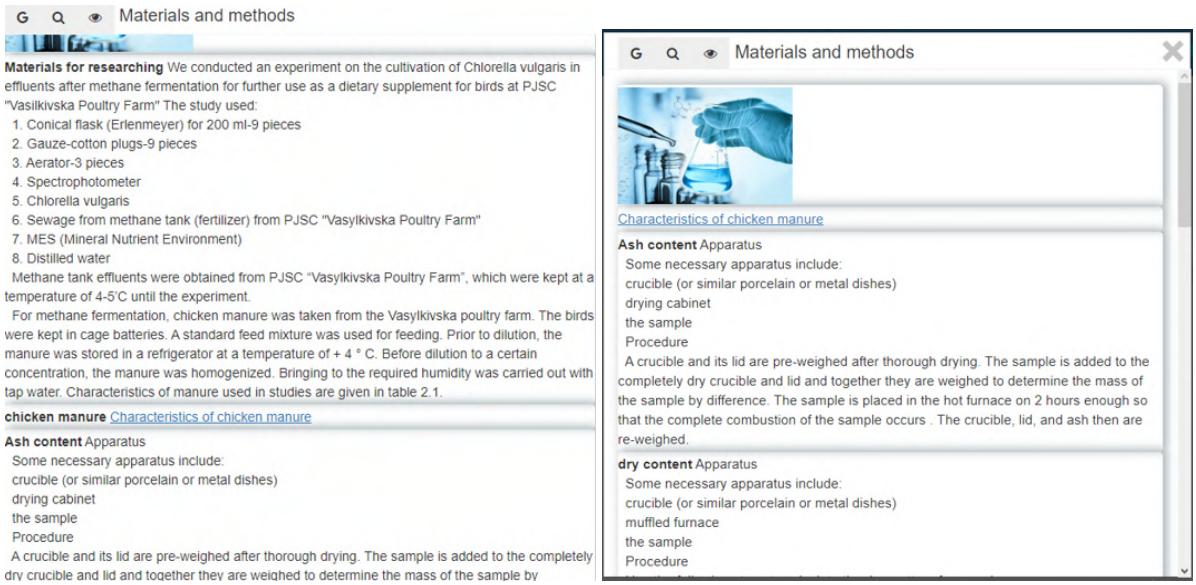
Table 4
Examples of the usage of the educational research element in ontology.

Element of the educational research	Example	The role of the node in the resulting graph	Using of the data
Title	**Node:** "Development a method for utilisation of anaerobic digestion effluent"	Parent node	Used only for structuration
Object	**Node:** Abstract **Class:** Object (object is only one per report) **Value:** Anaerobic digestion; **Value:** Microalgae's growth **Value:** Disposal of the waste	Located in Abstract node; each object presented as attribute	Used for the audit; to provide literature review; to link reports for each other with same data; to identify novelty and plagiarism
Subject	**Node:** Abstract **Class:** Subject **Value:** The processing of anaerobic digestion effluent into humates by the autocatalysis method	Located in Abstract node; each object presented as attribute	Same as previous
Hypothesis	**Node:** Abstract **Class:** Hypothesis **Value:** Effluent obtained after anaerobic digestion can be used as a nutrient medium for microalgae Chlorella Vulgaris	Located in Abstract node; each object presented as attribute	Same as previous
Keywords	**Node:** Abstract **Class:** Keywords **Value1:** Biogas; **Value2:** Anaerobic digestion **Value3:** Microalgae	Located in Abstract node; each object presented as attribute	Same as previous
Sections, Abstract, Introduction	**Node:** Introduction; **Class1:** Text; **Value1:** text itself; **Class2:** Biogas production in literature, ml/g of VS; **Value2:** 368; **Class3:** methane content, % ; **Value3:** 59	Each section presented in separated nodes; all text is presented in separate class of metadata, based on type of data	Used for representing of the main text of the educational reports; structuration and navigation
Materials and methods	**Node:** Materials and methods **Class1:** Method1; **Value1:** Desorption1; **Class2:** Method2; **Value2:** Desorption2	Located single node; each method is separated class of metadata	Used to provide links between the reports used same method by indexing and search
Concrete results and parameters of the research	**Node:** Results **Class1:** pH; **Value1:** 7.3; **Class2:** Decomposition, %; **Value2:** 87	Located a in separate node; each parameter is separated class of metadata	Used for the creation of the single ranking tool to systemise results from same field
Economic data	**Node:**Economic data **Class:** Payback period, years; **Value:** 5.3	Located the separate node; payback period presented in metadata	Used to provide comparison of the approaches to assess investment attractiveness
References	**Node:** Li et al. 2018, Chen 2003, Sergienko et al. 2016	Each report (paper) located in separate node	Used to link reports used same reference with each other

A separate node called "Abstract" has been created, which contains all the necessary metadata of

the work, such as “Object of the study”, “Subject of study”, “The aim of the study”, “Practical value”, “Scientific novelty”, “Keywords” and “Hypothesis of scientific works” in the form of the attributes. All metadata has been used to provide filtering and ranking.

The “Materials and methods” node, which contains all the materials, was used to perform the experiments. Every approach has been divided into the separate attribute of the node. This allows concentrating the reader’s attention, and it helps to process the data with each other. For further researchers, this mechanism will be described in detail. The general view of both works’ “Material and Methods” node is shown in figure 3 [29].



(a) (b)

Figure 3: The general view of a) research report “A” b) research report “B” “Materials and methods” node.

For each ontological node that duplicates sections of the research report, and that contain specific indicators after analysing, additional separate leaf nodes with these results have been created.

In this leaf node, all the issues are held in the form of semantic and numeric data. These results are automatically available for filtering, auditing and ranking. An example of this leaf node is shown in figure 4.

5. Information processing of the research report using Polyhedron tools

5.1. Using an audit tool to test a hypothesis

The audit tool [23, 24, 25] can be used to compare the hypotheses, subjects, objects of research, keywords, and other parameters of the research reports. To demonstrate the capabilities of the audit tool, the focus is on auditing only hypotheses. “A” model version of the “standard” ontology has been created, which contains metadata from the “Abstract” node of the research reports “A” ontological graph. This ontology had a simple structure without branches, with the parent node being named “Abstract”. The child nodes duplicate metadata from the “Abstract” node of the research reports “A”.

The “comparison” ontology has been created with the child nodes, which contain the following hypothesis: the effluent obtained after anaerobic digestion can be used as a nutrient medium for microalgae Spirulina Platensis (hypothesis 1), and the effluent obtained after anaerobic digestion can be used as a nutrient medium for microalgae Chlorella Vulgaris (hypothesis 2), the effluent obtained after anaerobic digestion cannot use it as a nutrient medium for microalgae Chlorella Vulgaris (hypothesis 3). The hypothesis 2 node also contains some metadata. This ontology also had a simple structure without

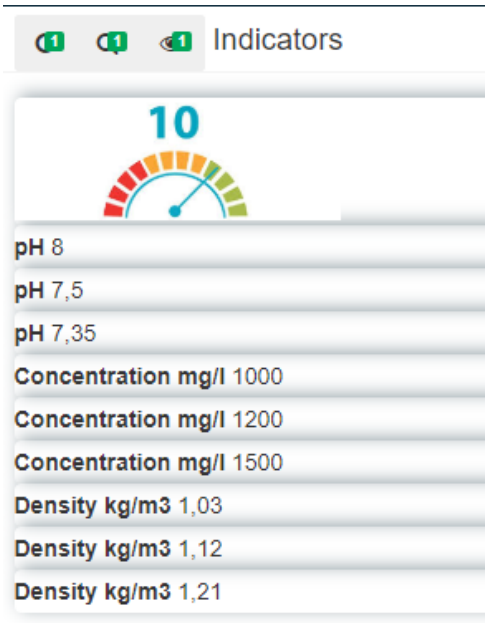
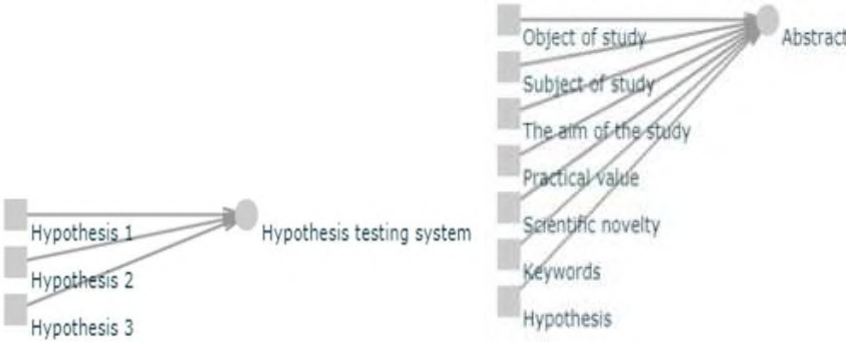


Figure 4: An example of leaf node with indicators after analysing.



(a) (b)

Figure 5: General view of in the taxonomic form the ontology of the comparing" (a) and (b) the ontology of the "standard".

branches with the parent node, the "Hypothesis test system". The general view of the obtained ontology of the comparison and the ontology of the standard in taxonomic form is shown in figure 5.

The system has checked whether the hypothesis is true or false by using the audit function. Those indicators which do not correspond to the standard have been coloured red. Thus, this solution will allow testing the idea of these scientific works and checking other metadata that have already been set by using information from the "Abstract" node (figure 5b).

5.2. Analysing of the research reports result on the practice value

Research report "A" and research report "B" have been compared with each other by the following criteria "Short-term economic perspective", "Long-term economic prospects". According to section 2 of the research report "A", the payback period of project "A" is five years, which corresponds to 6 points according to the criterion "Economic attractiveness". This parameter is better for the project described in report "B" with a payback period of four years and three months, which corresponds to 5 points on "Economic attractiveness". The system provides raking of the results. If there is a large amount of data, the instrument will be helpful to quickly and effectively evaluate the projects on "Economic attractiveness". Besides, in further research, the other criteria will be justified and used to provide data

management on the educational research, which will make the tool more functional.

Hypothesis testing system
(Аудит)

Враховуються властивості

#	Показники	Одиниця виміру	ДСТУ	Зразки		
				supposition 1	supposition 2	supposition 3
Abstract						
1	Object of study	Object of study	Chlorella vulgaris		Chlorella vulgaris	
2	Subject of study	Subject of study	Cultivation of Chlorella vulgaris microalgae on effluents obtained after methane fermentation.		Cultivation of Chlorella vulgaris microalgae on effluents obtained after methane fermentation.	
3	The aim of the study	The aim of the study	Developing a method of growing Chlorella Vulgaris in effluents after methane fermentation.		Developing a method of growing Chlorella Vulgaris in effluents after methane fermentation.	
4	Practical value	Practical value	The results of this work will contribute to the spread of biogas technologies. This approach makes it possible to increase the economic benefits from the utilization of bird droppings by converting the anaerobic digestion effluents into microalgae that have a wide range of applications.		The results of this work will contribute to the spread of biogas technologies. This approach makes it possible to increase the economic benefits from the utilization of bird droppings by converting the anaerobic digestion effluents into microalgae that have a wide range of applications.	
5	Scientific novelty	Scientific novelty	A method of utilization of methane tank effluent using microalgae is proposed. Cultures of Chlorella Vulgaris were adapted to the methane tank effluent.		A method of utilization of methane tank effluent using microalgae is proposed. Cultures of Chlorella Vulgaris were adapted to the methane tank effluent.	
6	Keywords	Keywords	microalgae		Chlorella Vulgaris	
7	Hypothesis	Hypothesis	The effluent obtained after anaerobic digestion can be used as a nutrient medium for microalgae Chlorella Vulgaris.	The effluent obtained after anaerobic digestion can be used as a nutrient medium for microalgae Spirulina Platensis.	The effluent obtained after anaerobic digestion can be used as a nutrient medium for microalgae Chlorella Vulgaris.	The effluent obtained after anaerobic digestion can not used it as a nutrient medium for microalgae Chlorella Vulgaris.

Figure 6: General view of the audit results in the “Hypothesis test system” ontology.

Postion	Name	Short ecomonic perspective, points
1	**Development a method for utilization of methane tank effluent** 	8
2	**Development of a rational way for utilization of meta-tank waste at PJSC Vasylkivska poultry farm** 	6

Figure 7: General view of the ranking result.

5.3. The role of taxonomies of educational studies in centralised informational web-oriented educational environment

5.3.1. Mathematical interoperation of integration of taxonomies of educational studies in centralised informational web-oriented educational environment

As it was shown before, the preleaf nodes (L4) are terms (main ontology elements) that are very promising to use in terms of interoperability with other ontologies of subject areas, for example, with educational programmes that in that term will be the additional instrument for Centralised informational web-oriented educational environment.

So, such connection with the centralised informational web-oriented educational environment concept and ensuring interdisciplinarity is described by formulas. Each ontology is based on the conceptualisation of terms. It means that each ontology is described as a tuple (cortege) of terms from the field it contains:

$$O_i =< t_i > \tag{9}$$

So, we can describe ontology of educational programme, ontology of equipment that being used, ontology of method and ontology of educational studies as further:

$$O_1 = t_1, t_2, t_3, t_4, t_5 \tag{10}$$

$$O_2 = t_1, t_3, t_5, t_6 \tag{11}$$

$$O_3 = t_3, t_5, t_6, t_7 \tag{12}$$

$$O_4 = t_1, t_3, t_8, t_9, t_{10}, t_{11}, t_{12} \tag{13}$$

As seen for equations, some ontologies have cross-terms that will provide inoperability with CIWOEE and interdisciplinarity. The terms that are cross-terms will be used by the user to transfer from elements (nodes) of one ontology to aspects of another. For this example, leaf or sub-leaf (in the case of educational studies' ontology; such as specific methods, keywords, objects, etc.), t_1, t_3, and t_5 are cross-terms:

$$t_1 \in O_1, O_2, O_4 \tag{14}$$

$$t_3 \in O_1, O_2, O_3, O_4 \tag{15}$$

$$t_5 \in O_1, O_2, O_3 \tag{16}$$

5.3.2. Practical application of ontology-based integration of scientific studies educational programmes of centralised informational web-oriented educational environment

As shown in equations 10-13, the terms of scientific study ontology, such as specific methods, keywords, objects, etc., are used to provide a link with terms of educational programmes. Terms of studies that may be used to link the ontology of scientific studies with the ontology of educational programmes are shown in figure 8.

A similar situation is also related to educational programmes. There is an ontology that systemises the data on the knowledge field related to chemistry using schools' educational programmes. It also consists of terms that are presented in the form of nodes. The general view of academic programmes' ontology related to chemistry educational programmes in Ukraine and phrases that may be used to link with the ontology of scientific studies is shown in figure 9.

Therefore, some terms may be related to both educational programmes and scientific studies ontologies. In this case, such links allow using subnodes (keywords, methods, etc.) to find scientific studies related to this term. The exact words to provide interoperability between educational programmes ontology and scientific studies ontologies are shown in figure 10. As can be seen, the terms "methane" and "biogas" are related to both educational programmes and scientific studies and, therefore, they are used to link these ontologies.

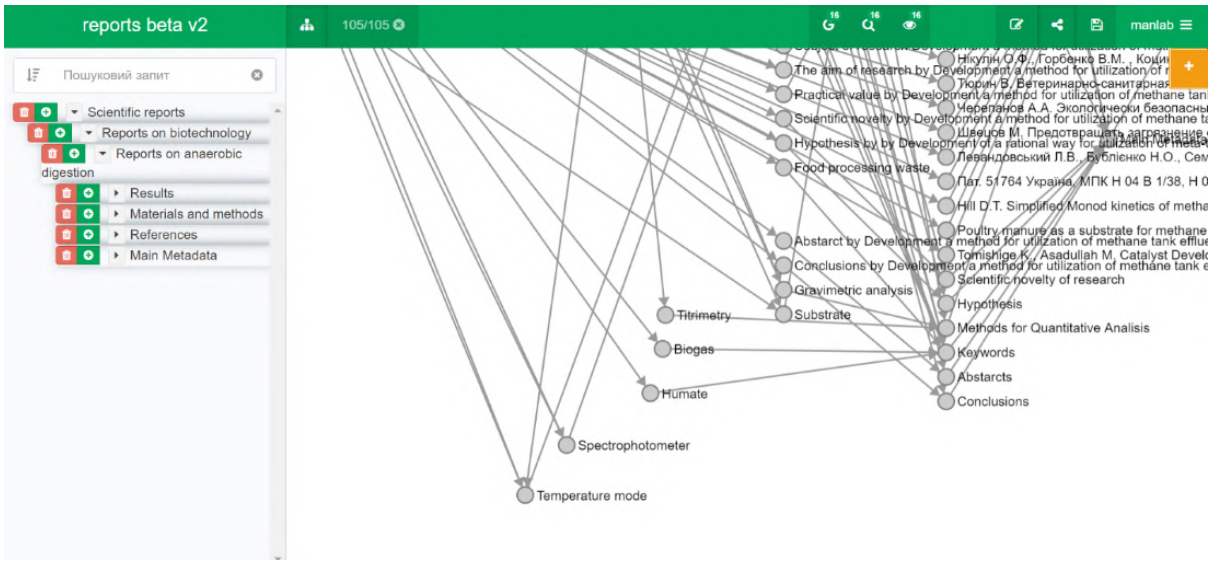


Figure 8: Terms of studies that may be used to link ontology of scientific studies with ontology of educational programmes.

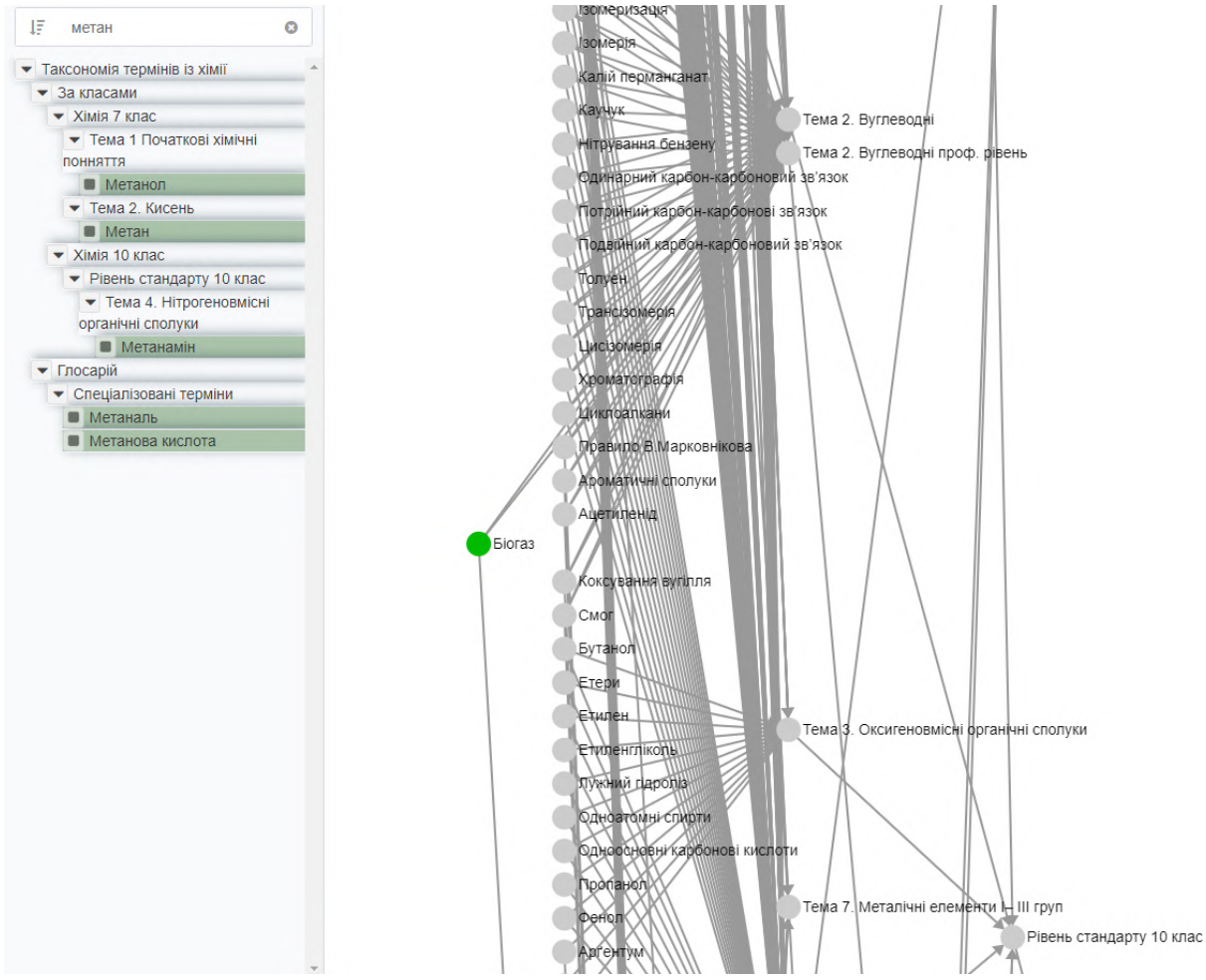


Figure 9: The general view of educational programmes' ontology related to chemistry educational programmes in Ukraine and terms that may be used to link with ontology of scientific studies.

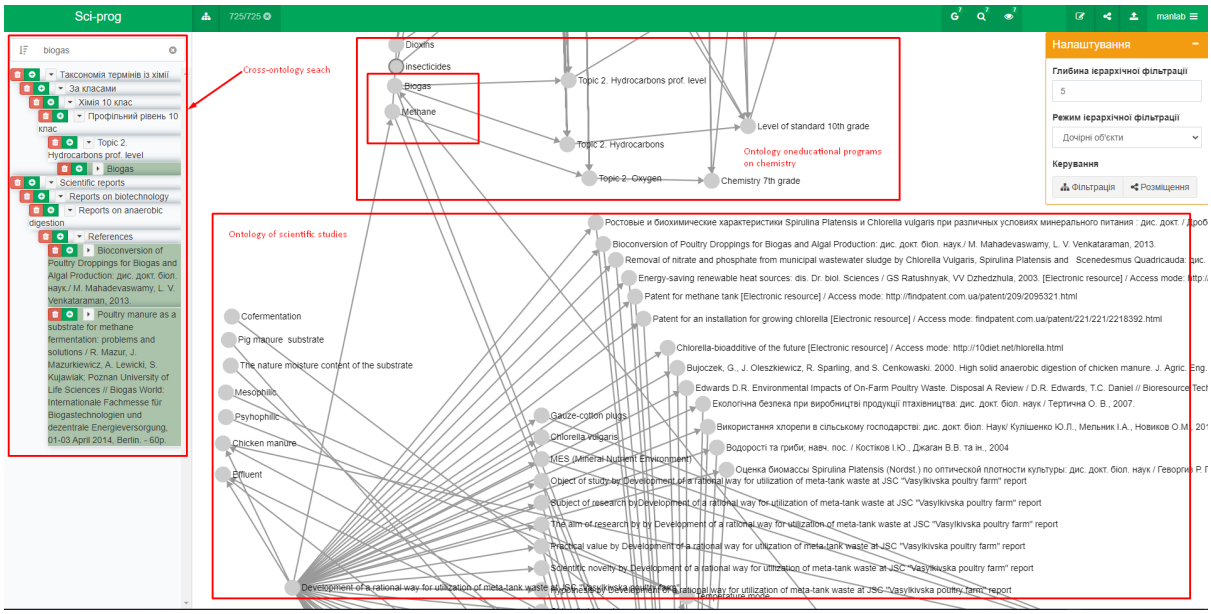


Figure 10: Using of same terms to provide interoperability between educational programmes ontology and scientific studies ontologies.

6. Discussion

The proposed database follows the "Leiden Manifesto for Scientometrics." In the obtained ontological database, quantitative evaluation can be supported by qualitative expert assessment. Additionally, this ontological database can unite the research missions of the institution, group, or researcher and protect excellence in internally relevant research. The ontological form of research reports can keep data collection and analytical processes open, transparent, and straightforward. Because all metadata is contained in a separate node that can be expanded and supplemented. Thus, the obtained ontological database can also account for variations, e.g., in publication and citation practices. It can provide a base assessment of individual researchers' qualitative judgement of their portfolios. Because all ontological graphs are validated by experts, in this way, it is possible to avoid misplaced concreteness, including false precision, and recognise the systemic effects of all assessments and indicators. In addition, indicators can be scrutinised regularly and updated in the obtained ontological database. Furthermore, the proposed ontology-based research reports can be integrated into a single environment – ontology repositories, as suggested before [39].

The process starts with paper creation. For this stage, we can use various text editors, for example, Word or Google Docs. Then an expert or author of the paper will formulate metadata, which is necessary for the ontology. For this purpose, the author will use Microsoft Excel or Google Sheets. Then, an editor needs to add information to the graph. In our case, the IT Platform Polyhedron is used for this. And last but not least, it is possible to use the "Alternative" system, which includes Audit, Filtering, and Ranking instruments. All proposed tools are illustrated in the workflow diagram figure 11.

It is worth mentioning that this methodology of the centralised information web-oriented educational environment of Ukraine has been developed, and with the ontological approach is more systematic now. Educational programmes are essential to the world picture that is given to people during education, so they contain all basic terms that may be used to systematise other fields of human activities, including scientific studies. Like researchers, pupils interested in terms can also use such specific term nodes to continue their studying by investigating the studies conducted.

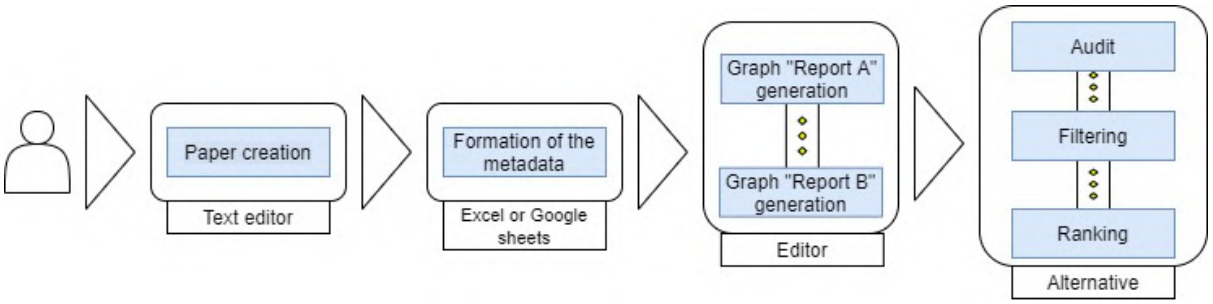


Figure 11: Workflow diagram of the creation of structured ontologies on scientific reports and their processing.

7. Conclusions

An ontological approach to scientific work systematisation has been proposed, assuring compatibility. A system for arranging research reports based on digital taxonomies (ontologies) has been created. It allows users to construct node hierarchies utilising the natural structure of the reports. Concrete parameters were added to the nodes as metadata (semantic, numeric, images, and links) to enable Polyhedron tools processing. Ranging and filtering were employed to handle semantic and numerical metadata. The obtained results allow for interchange across various study reports (including educational). The "Leiden Manifesto for Scientometrics" is the acknowledged ontological method.

Further study will improve interoperability across research works by developing a single taxonomy that provides hierarchisation using the same methodologies, literature, and report findings and its processing using both methods suggested in the research and newly developed ones.

For the first time, it presents the concept of integration of scientific studies ontologies with educational programmes that make them more usable for both students and young researchers. The proposed approach aligns with the centralised informational web-oriented educational environment concept.

Declaration on Generative AI: The authors have not employed any Generative AI tools.

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A novel pedagogical approach to equipping prospective IT professionals with skills in 3D modelling and reconstruction of architectural heritage

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Abstract

This paper presents a novel pedagogical methodology developed and tested for teaching prospective IT professionals cutting-edge 3D technologies for graphical reconstruction of architectural heritage. The effectiveness of the proposed approach is demonstrated through a case study involving the reconstruction of the Parochial Cathedral of St Mary of Perpetual Assistance from the 1950s. The methodology encompasses a comprehensive set of stages: analysis, modelling, design, and 3D printing, underpinned by a synthesis of archival data analysis, parallax estimation from stereo image pairs, and contemporary 3D modelling techniques. 3DS Max was selected as the optimal software for creating the detailed 3D model, while Cura was employed to prepare the model for 3D printing. The experimental evaluation confirmed the efficacy of the proposed teaching methodology in equipping students with a robust theoretical and practical foundation for deploying modern digital technologies in the reconstruction and preservation of architectural heritage. This work makes a significant contribution to the pedagogy of IT and digital heritage conservation.

Keywords

architectural heritage, 3D reconstruction, pedagogy, IT education, digital technologies

1. Introduction

The rapid advancement and pervasive integration of digital technologies across all domains of human endeavour necessitates a re-evaluation of the substance and methodology of educating IT professionals, particularly those engaged in environmental object design. In this context, 3D technologies are emerging as a crucial component of modern education, offering novel opportunities for their application in the graphical reconstruction of architectural heritage [1].

3D graphics empowers the creation of spatial models of diverse objects, faithfully replicating their geometric forms and material textures [2, 3, 4, 5]. Notably, 3D technologies can digitally resurrect architectural artefacts that have been lost to time [6], facilitating detailed analysis of architectural features, reconstruction of object structures, and generation of highly realistic models. The significance of this research domain is underscored by the "Declaration of Cooperation on advancing the digitisation of cultural heritage", endorsed by 27 European nations [7]. Specifically, the European Commission's expert group on cultural heritage digitisation has formulated comprehensive guidelines for holistic 3D documentation of Europe's cultural heritage sites [8].

3D modelling enables the assessment of an object's technical and physical properties prior to fabricating a physical prototype. Model analysis techniques allow for the examination of dimensions, materials,

AREdu 2024: 7th International Workshop on Augmented Reality in Education, May 14, 2024, Kryvyi Rih, Ukraine
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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

CEUR-WS.org/Vol-3918/paper026.pdf

and constituent elements.

Conventionally, object or project concepts are communicated through videos or images based on 3D graphics. However, this imposes limitations on user interaction, as static images preclude scenario manipulation or detailed inspection.

The confluence of advancements in 3D graphics and computational capabilities has enabled the real-time rendering of complex scenes without compromising speed or quality. This has piqued the interest of professionals across various fields in the potential applications of 3D visualisation.

In the realm of architecture and civil engineering, virtual buildings with immersive interiors and virtual cities are gaining traction. Photorealistic object reconstruction facilitates the utilisation of object models in museum, reconstruction, and commercial projects, as well as in educational contexts [9].

The preservation and dissemination of cultural heritage are paramount for contemporary society. The evolution of computers and 3D graphical tools has made it possible to conserve cultural achievements not merely as images or photographs, but as models in their original form or as digital replicas of physical objects [10].

Numerous architectural monuments have vanished, leaving no traces of dimensions, plans, or photographic records. For such historical structures, graphical reconstruction serves as the sole means of resurrecting the lost or destroyed architectural object from a specific time period. Graphical reconstruction of historical architectural heritage encapsulates the totality of contemporary knowledge concerning the object [11].

In recent years, there has been a proliferation of museums, including virtual ones, showcasing digitised artefacts. These museums provide detailed insights into historical achievements, their origins, and contribute to the cultural advancement of society.

Consequently, the study of 3D technologies for the graphical reconstruction of architectural heritage by prospective IT professionals constitutes a crucial area of research within the broader context of their professional training.

2. Related work

A substantial body of scientific and pedagogical research has been dedicated to the application of 3D technologies in the training of prospective IT professionals. The selection of software for 3D modelling and associated workflows are described by Osadcha and Chemerys [12]. The role of 3D modelling in architectural design is explored in the works of Borodkin [9], Rumyantsev et al. [10], Rozhko [11].

3D modelling as a tool for design and architecture is indirectly addressed in publications by Danylenko [13].

Despite this, studies focused on the theory and methods of engineering and graphical education of students (Holub et al. [14], Korniienko et al. [15], Kuznietsov and Moiseienko [16], Lavrentieva et al. [17], Modlo et al. [18, 19], Morkun et al. [20], Rashevska and Soloviev [21], Shepiliev et al. [22, 23], Sitsylitsyn et al. [24], Striuk and Semerikov [25], Striuk et al. [26], Tkachuk et al. [27], Zelinska et al. [28]. Babkin et al. [29], Chemerys and Osadcha [30], Korotun et al. [31], Lehka and Shokaliuk [32], Markova et al. [33], Ozhha [34], Osadchyi et al. [35], Semerikov et al. [36], Striuk and Semerikov [37], Vakaliuk et al. [38, 39, 40], Varava et al. [41] examined the issues of professional training of prospective IT specialists.

However, the challenge of teaching 3D technologies to prospective IT professionals possesses distinct theoretical and methodological nuances, as it demands consideration within the context of a specifically graphical domain. To effectively cultivate students' practical skills in modelling and printing 3D objects, it is imperative to integrate the study of such technologies as an essential component of their educational journey [42, 43].

The intricacies of creating and deploying 3D models of historical architectural objects in educational settings are investigated in the works of Milkova et al. [44], Maietti et al. [45]. The capabilities of 3D modelling tools in the computer-based reconstruction of historical and cultural heritage objects are the focus of studies by Butnariu et al. [46], Kotsiubivska and Baranskyi [47], Riabokon [48].

Nevertheless, it is important to note that comprehensive scientific approaches to the methodology of employing 3D technologies in the graphical reconstruction of architectural heritage, as an integral facet of the professional training of prospective IT specialists, remain underexplored.

Thus, analysis of the literature reveals the necessity for further scientific inquiry into 3D technologies for the graphical reconstruction of architectural heritage and the development of pertinent guidelines for training future professionals.

The relevance of this issue led to the articulation of the paper's objective – to demonstrate the efficacy of the methodology for teaching prospective IT specialists cutting-edge 3D technologies for the graphical reconstruction of architectural heritage.

The research object is the process of teaching 3D technologies for the graphical reconstruction of architectural heritage in the preparation of prospective IT specialists, as exemplified by the creation and printing of a 3D model of the Parochial Cathedral of St Mary.

The novelty of the research lies in the proposal of a comprehensive methodology for studying the graphical reconstruction of historical architectural objects. This methodology involves developing skills in constructing a 3D model of an object based on design technologies in conjunction with image analysis using parallax estimation from a stereo pair data array of images of the studied objects.

3. Methodology

3.1. Rationale for teaching methods in 3D reconstruction

The experts of the Declaration on the Promotion of the Digitisation of Cultural Heritage recommend the inclusion of 3D technology skills as part of the core knowledge of IT professionals involved in cultural heritage restoration [8]. Graphical reconstruction professionals must possess the requisite knowledge and skills to effectively design a project, preserve raw data, and 3D layouts. To address this need, the development of training courses for the study of 3D technologies in the context of cultural heritage preservation or 3D technologies in general is crucial.

Proficiency in employing 3D technologies for the graphical reconstruction of architectural heritage is a vital component of the professional training of prospective IT professionals, equipping them with practical skills in 3D technologies that are highly sought after in the contemporary job market.

Therefore, based on the conducted research, we propose a methodology for teaching graphical 3D reconstruction. This methodology aims to foster a system of theoretical and practical knowledge among students for designing buildings and structures using modern digital technologies for graphical reconstruction.

The proposed methodology is grounded in the following principles: systematic and consistent approach, accessibility, clarity, connection between theory and practice, and a blend of individual and collective learning.

The principle of a systematic and consistent approach involves the structured formation of knowledge, skills, and abilities, ensuring that each lesson is interconnected and new knowledge builds upon previously acquired knowledge while laying the foundation for subsequent learning. Within each topic, the complexity of the material gradually increases. The logical culmination of the course is the implementation of a group project, through which students refine and consolidate their knowledge and experience teamwork.

The principle of accessibility ensures that the forms, methods, and content align with the students' capabilities and their level of knowledge in the field. Therefore, students should already possess an understanding of graphics and have learned to construct simple models before progressing to the modelling of complex objects.

The principle of clarity is directly applied in the classroom: the instructor demonstrates how to build individual elements in the software, and after a short period, students are assigned the task of replicating the process. This approach encourages attentiveness to enable task completion and cultivates interest in the course.

The principle of connecting theory and practice is realised when students perform laboratory work or tasks of various types, preceded by the study of relevant theory.

The final principle is the combination of individual and collective learning. It encompasses not only individual work but also tasks that require group collaboration. This approach facilitates knowledge exchange among students and fosters active listening skills to efficiently complete assignments.

Considering the alignment with the established objectives, we deem it appropriate to divide the methodology of graphical reconstruction of architectural objects using 3D technologies into the following main stages: analysis, modelling, design, and model printing (figure 1).

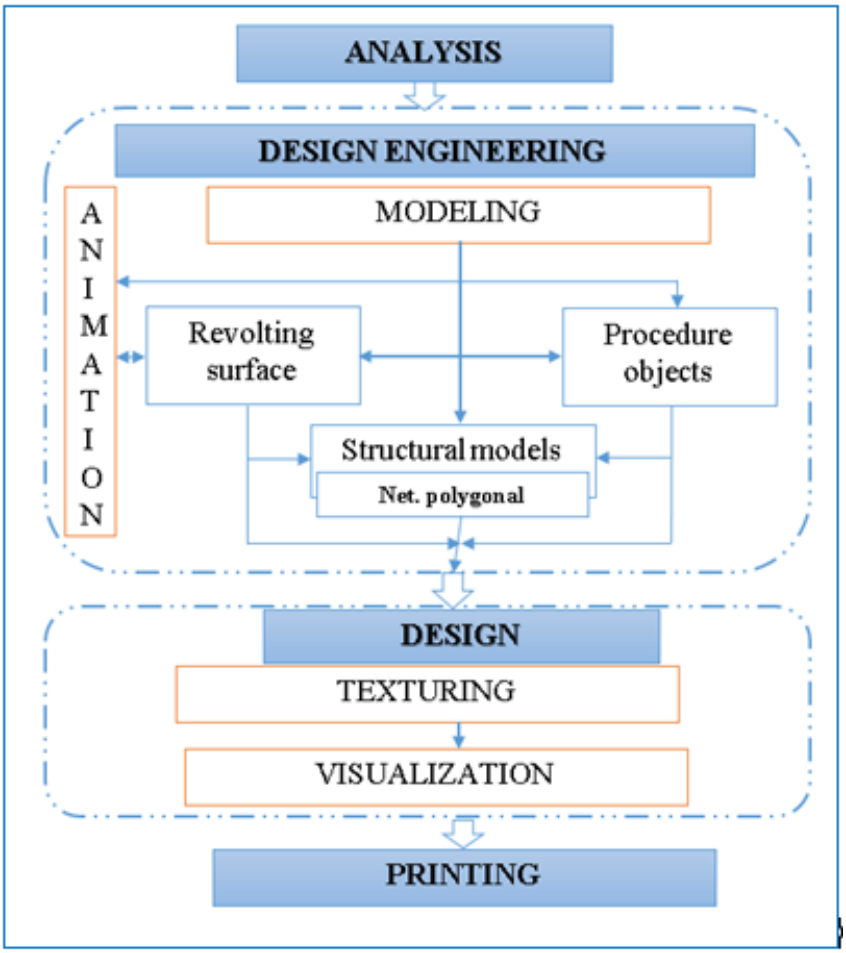


Figure 1: Stages of project development.

During the analysis stage, students gather the necessary data about the object and the operations required to build a 3D model. Solving such problems enables students to develop analytical skills and a creative approach to object synthesis based on available information.

The modelling stage encompasses the process of creating a 3D model and animation (driving existing models or adding and moving additional cameras along specific trajectories). At this stage, students cultivate engineering skills through the utilisation of modern software tools and associated techniques.

The design stage involves texturing and rendering. Solving design problems allows students to develop the ability to compose objects while adhering to colour schemes, select materials and textures, choose light sources, and adjust camera angles.

The final stage of the methodology is the production of a model using 3D printing. At this stage, students acquire technological skills in working with modern equipment, including setting the parameters of the 3D printing process, calibrating the printer table, and selecting printing materials.

Thus, we consider it expedient to provide a detailed account of the implementation of each stage using the example of creating a 3D model of the Parochial Cathedral and to substantiate the effectiveness

of the proposed methodology.

3.2. Sequence and content of the analytical stage

3D modelling is a distinct domain of computer graphics that incorporates essential tools and techniques for constructing a model of an object in 3D space. The 3D modelling techniques for a graphical object comprise the following main cycles: the analytical cycle (collection of input materials; calculation of object dimensions and parameters) and the modelling cycle (drafting the object form; accumulation, carving, stamping, etc.).

Currently, 3D modelling finds application in virtually all domains of human activity, including advertising, marketing, industry, computer games, cinema, architecture, design, and animation. 3D models of buildings and facilities form an integral part of modern design, serving as the foundation for creating highly detailed object prototypes.

The stages of constructing 3D models of monuments and landscapes are specific in nature, contingent upon the defined objectives and selected software. However, the essential components of the methodologies are common across different modelling objects. When defining a modelling task, it is crucial to determine the required level of detail and realism of the final product [49]. The realism of a model is contingent upon the selected materials for texture mapping onto the object. Virtual 3D modelling for architectural structures is predicated on solving the task of efficient layout, which is prevalent in pattern recognition theory.

Presently, there exists a wide array of software tools with varying parameters and applications in computer graphics. The choice of software is primarily dictated by the task at hand. After identifying the functions and tools necessary for task completion, it is essential to select the most suitable software for constructing 3D models.

Architects and designers extensively leverage 3D graphics technologies due to their efficiency and ease of use in project implementation. To determine the most appropriate software environment, a survey was conducted among experts in the field and students studying the fundamentals of 3D modelling. Based on the survey results, the following software products were identified as the most popular: Blender, 3D Max, SweetHome 3D, SketchUpMake, Pro 100, FloorPlan 3D, ARCON 3D Architect, ArchiCAD, Maya, LUMION, and Cinema 4D. It is worth noting that SweetHome 3D, 3DS Max, FloorPlan 3D, ARCON 3D Architect, and ArchiCAD are particularly well-suited for architectural applications [12].

As our objective is to construct an object model, we must analyse the aforementioned software to select the most appropriate tool. The evaluation quality parameters are chosen in accordance with the ISO 9126:2001 Standard, wherein each characteristic is described by several attributes [13]. In this case, the criteria include functionality, user-friendliness, efficiency, program interface, and render quality (the final image after processing) as the most critical parameter. Given that these criteria are not equivalent, importance factors are assigned to each of them based on their relevance to the defined task (Table 1).

Table 1
Assessment parameters.

Parameter	Importance factor
Functionality	3
User-friendliness	2
Efficiency	2.5
Program interface	1.5
Render quality	4

The evaluation is performed on a scale of 1 to 10 points for each parameter based on experience with similar software. Thus, in assessing the characteristics of software that would be advisable for the graphical 3D reconstruction of architectural objects, we obtained the following rating results: FloorPlan 3D – 44 points, ARCON 3D Architect – 50, SweetHome 3D – 80, ArchiCAD – 97, and 3ds Max – 135 points.

According to the rating, it was determined that 3ds Max and ArchiCAD are the most convenient and effective for graphical 3D reconstruction, offering a user-friendly and efficient workflow. However, the final model renders produced by the 3DS Max system are of significantly higher quality. Therefore, the 3DS Max environment was chosen to create the Cathedral model, as it possesses all the necessary tools for rendering with a high degree of realism.

Graphical reconstruction of lost or destroyed architectural objects is a specific type of activity aimed at studying these objects to restore their appearance at the time of their existence using 3D graphics tools, guided by preserved documents, plans, or photographs [9, 11].

Graphical reconstruction assumes the absence of precise data on an object from a single data source. It is employed to restore a lost appearance by means of graphical and documentary data through collecting and combining information from various sources. As an activity, graphical reconstruction is conceptualised as a set of operations encompassing data collection, object investigation, and fixation prior to modelling options of a destroyed architectural monument.

The Parochial Cathedral of St Mary of Perpetual Assistance from the 1950s (hereafter referred to as the Parochial Cathedral) is one of the lost historical objects of Ternopil that adorned the city centre at the corner of Ruska and Mitskevich Streets (present-day Shevchenko Boulevard). Photographs and plans serve as the primary data sources concerning the Cathedral.

The historical and architectural key plan of Ternopil indicates that "the majestic and delicate building in the neo-Gothic style was striking in its beauty and perfection. The slim tower-spire, soaring 62m high, hovered over the city as if striving upward into the sky. It was even used as a fire tower, built upon the project of the famous Lviv architect Professor Theodor Marian Talʻovskyi" [50].

Boitsun [51] recounts that "in 1954, there were several days of explosions heard when the Catholic Church was blasted. In 1959, a supermarket was opened there to celebrate the anniversary of the October Revolution. Many elements of the Church ornamentation were taken to Poland. Part of the high reliefs of the sacred procession and the sculpture of Madonna were preserved in the Medium Church (the Church of the Nativity of Christ)" [51]. Consequently, we consider it of great importance to restore this architectural monument to preserve Ternopil's cultural heritage.

3.3. Methodology of the modelling stage

The creation of a 3D model of an object from its two-dimensional projections (photographs), i.e., its 3D reconstruction, is carried out according to the following basic techniques: using design with 3D scanners, obtaining a sequential series of images of an object from all sides, and using a stereo pair [52].

It is a priori impossible to employ the 3D scanning technique for the graphical reconstruction of lost historical architectural objects. Therefore, we consider it inappropriate to consider this technique.

Graphical reconstruction by design involves the creation of a digital model using specialised software products. When creating a model, one can utilise existing drawings or develop new ones. Thus, it is possible to reproduce various objects that already exist in the real world, create those that have not yet been built, or carry out a graphical reconstruction of those that have been destroyed. This reconstruction method provides for modelling in various ways: based on primitives, sections, Boolean operations, and arbitrary surfaces constructed using various mathematical models.

This method offers several advantages, one of which is construction accuracy. However, for the reconstruction of lost historical architectural objects, this method requires additional information, as there are often insufficient drawings and plans of the area and the building. Therefore, it is advisable to combine it with the method of graphical reconstruction based on a set of images of an object from different sides.

The method of graphical reconstruction of an object from a set of images uses a sequential series of its images. In this case, the required percentage of overlap between two adjacent frames should exceed half, and the minimum number of overlapping frames is equal to three.

The algorithm for implementing this method consists of the following stages:

1) Analysis of photographs of the object under study;

2) Search for singular points and solution of a system of equations obtained based on a set of data points;
3) Search for "identical" points on different sets of adjacent images of an object;
4) Calculation of the coordinates of points from the "base" image of the object;
5) Mapping of points in the coordinate system most convenient for object analysis and structure imposition.

The disadvantage of this method is the need for a large number of photographs for analysis to obtain high-quality results of graphical reconstruction.

To address the issue of insufficient graphical information based on image analysis, we propose using the method of graphical reconstruction using a stereo pair. This method is based on obtaining and processing a set of pairs of images. In this case, the selection of correspondence points, their comparison, and geometric transformations are carried out. Obtaining a pair or series of images in which parallax is observed is the main task of this method. To build a 3D model, one needs to perform the following algorithm of actions: determining the fundamental matrix, finding the corresponding points, building a point cloud, and texturing. However, the model built using this method cannot be considered a full-fledged method of graphical reconstruction, as it only constructs a surface view of the object.

Based on the analysis, we have proposed a comprehensive methodology for the graphical reconstruction of historical architectural objects for the implementation of the modelling stage. This technique consists of constructing a 3D model of an object based on modern 3D design technologies, using methods for analysing archival descriptive information and data on a set of images, and processing technology for a stereo pair data array.

According to our proposed methodology for constructing a 3D model for the graphical reconstruction of a historical building, it is carried out based on the cyclical execution of the following stages [53]:

1. Search for information to create an accurate model from a set of images.
2. Creation of a model in the 3DS Max software environment.
3. Selection of the correct dimensions and construction of small parts diagrams based on the analysis of parallax image evaluation.

Thus, the programmed reconstruction process provided for the restoration of the building according to the data indicated in the sources (description, photographs, drawings), as well as based on certain parameters according to the comparison of descriptions and data on the construction technologies of cathedrals of that time. The construction of a 3D model is based on a stereo pair layout of the image of the destroyed Parochial Cathedral.

To restore the spatial configuration of objects, a parallax estimation of images was carried out. The principle of this assessment is that after processing a pair of stereo images, for each element of the left image, the corresponding element is found on the right image. The difference in the horizontal coordinates of the corresponding points (parallax) qualitatively reflects the distance to the image point [48].

Data collection involves searching for cartographic materials as well as images and texts to facilitate the accomplishment of the set task. Digital data are preferable, followed by vector and raster images. While searching for information, we use a photograph of the Parochial Cathedral with sharp images of elements of the architectural object to create its precise model (figure 2).

In applying 3D modelling methods, special attention is paid to geometrical modelling considering the type of the modelled object (engineering, design, architectural, etc.) and the technology applied [54].

Guided by a detailed analysis of over 20 photographs of the Cathedral and its layout, we build a 3D model of the object. Thus, the above-described procedures result in a primary platform for the model.

The next actions are aimed at editing the forms of the basis according to the available photographs. After completing a detailed analysis of sizes and architectural features, we make amendments using relevant 3DS Max tools [55]. After that, the building acquires a more realistic appearance. The complex character of building the model involves numerous fine details, their asymmetry, and location in different planes.

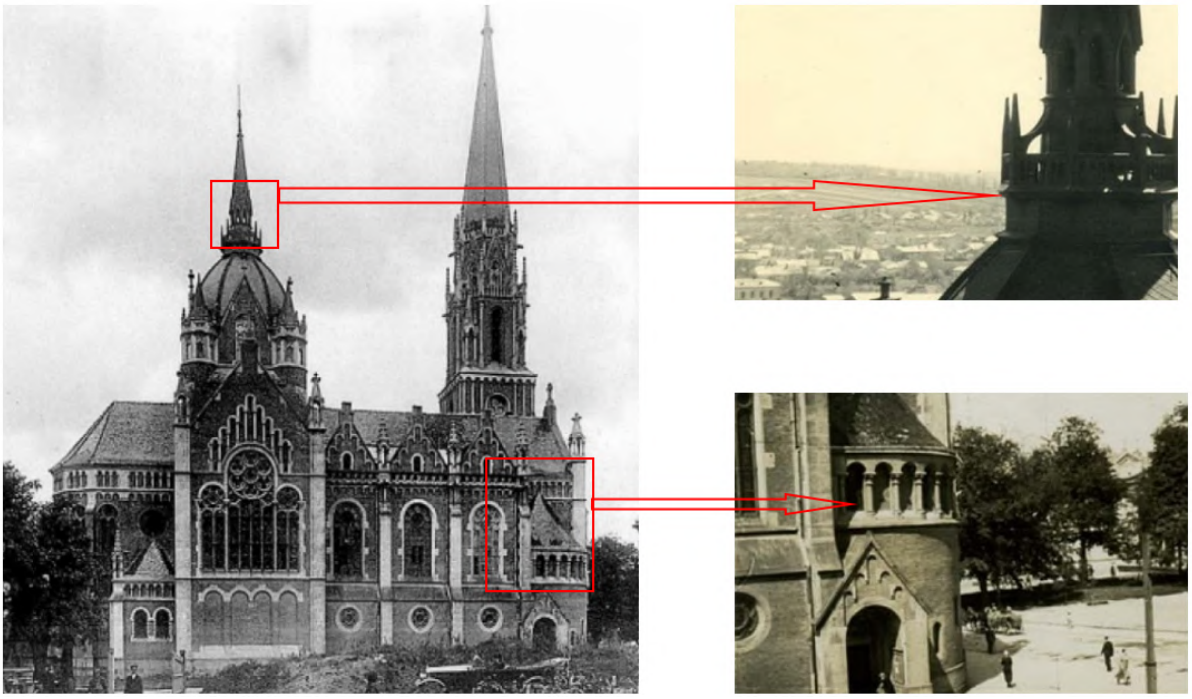


Figure 2: Analysis of the spatial configuration and details of the Parochial Cathedral of St Mary.

Next, we perform detailed processing of walls and domes. To reduce labour-intensive procedures of model building, repeated details like windows can be copied and dragged to the required location. If resizing the element, its plane, or angle is needed, it can be done using the functions of the software environment.

3.4. Implementation of the design stage

For the sake of convenience, we apply appropriate functions for revolving and moving the model. Thus, after completing a series of actions and operations, we obtain a 3D model of the Parochial Cathedral. To make the image of the model more realistic, we perform its rendering.

Rendering is responsible for applying various special effects, detailing, and fine-tuning components. A texture map is also prepared. First, materials are assigned, after which parameters such as roughness, reflection, and transparency are set. Additionally, light sources and cameras are positioned. So, at this stage, the 3D visualisation settings are clarified and adjusted.

The primary and resulting 3D models of the cathedral after the stage of analysing the dimensions and features of the architecture are shown in figure 3.

Before creating a printed miniature of the 3D model, we should analyse and adjust it properly. As the target result of modelling is a printed miniature, the built model should be exported into the STL format. It is worth noting that due to the intensive development of 3D printing, most specialised programs support this feature. This type supports 3D objects by preserving them as a bulk of triangular data describing a surface.

3.5. Sequence and content of the 3D printing stage

The first stage of preparing the model for printing involves analysing the 3D model geometry, which includes testing for open spaces in the polygonal net, displacement of polygons, and defects in geometry.

The next stage includes an analysis of all parameters, sizes, and their conformity with printing materials. As the built 3D model has the dimensions of a real-life building, it requires scaling to create its printable miniature (figure 4).

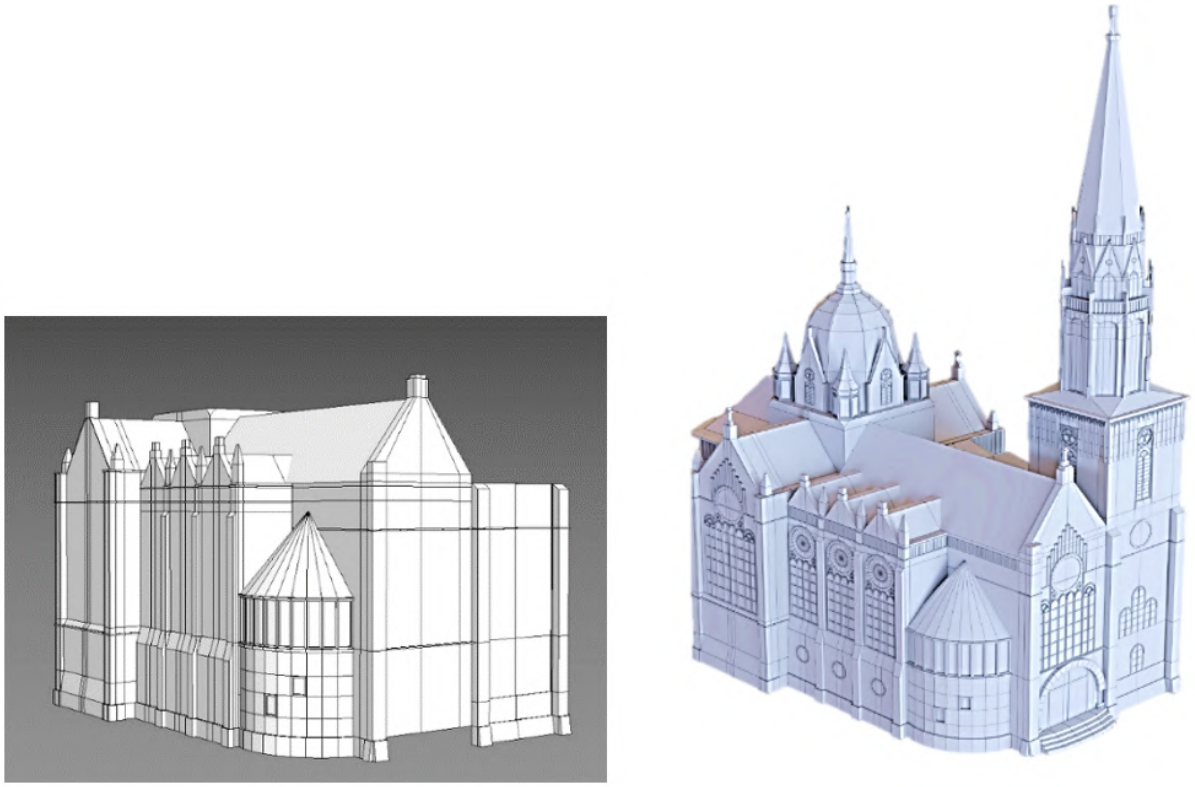


Figure 3: The primary and resulting 3D models of the Parochial Cathedral.

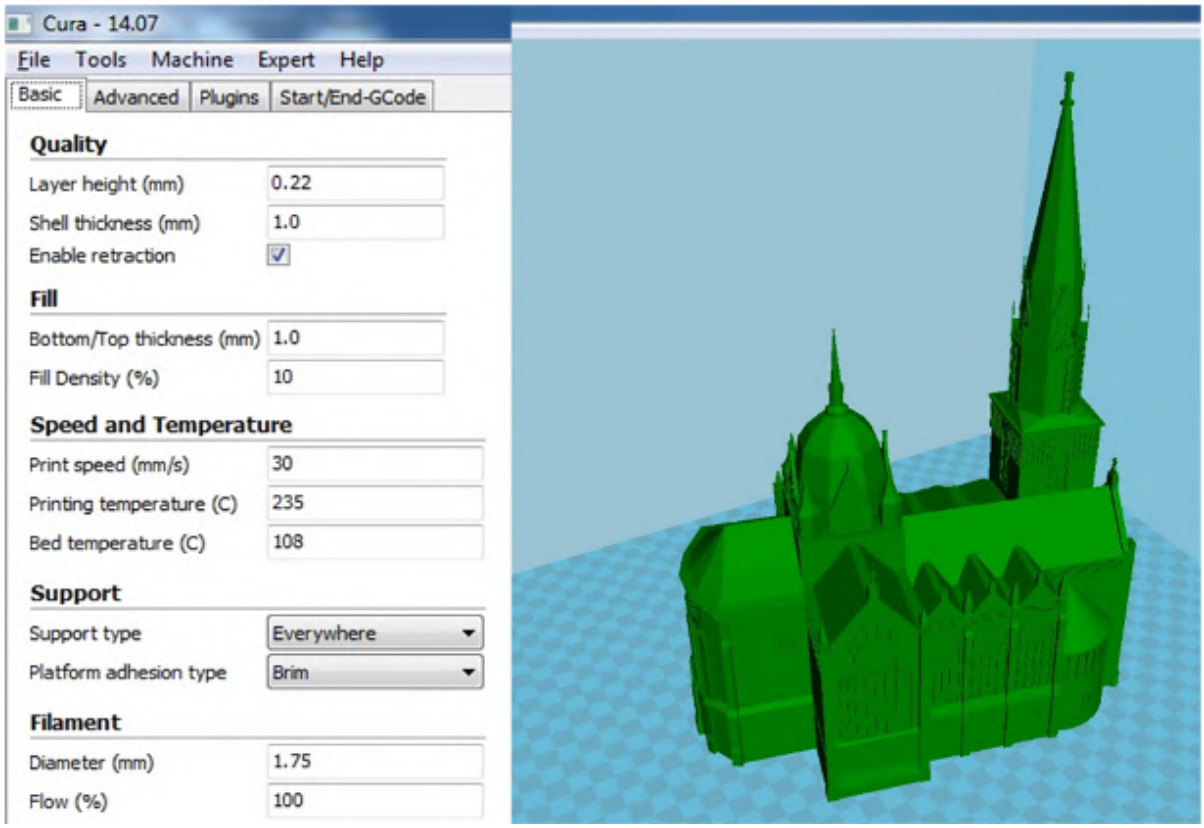


Figure 4: Adjusting the model sizes for printing.

Nowadays, there is a great variety of software for 3D printing, among which one should mention Cura, CraftWare, Slic3r, 3DTin, and Repetier-Host. These software products are quite widespread due to their advanced features and relative complexity.

Yet, guided by convenience and a relatively user-friendly interface, we apply Cura, which, apart from standard editing tools, printing quality adjustment, and material parameters, includes functions for calculating the weight of the end item, its print time, etc. [56].

Basic settings of technological parameters include printing quality, filling, printing speed and temperature, parameters of printing support, and plastic threads. When setting the parameters of printing quality, the most essential one is the layer height (mm), determined by the nozzle diameter, and it should not exceed half of it.

Shell thickness (mm) determines the thickness of the printing walls of thin-walled objects or objects with a reduced infill ratio. Shell thickness is determined by corresponding geometrical parameters of an object. For small models, a thickness of 10–30 mm is optimal.

Economic factors of plastic consumption are determined by fill density (%). In most cases, the infill ratio is 10%, yet, for inflexible models and considering structural features of a model, the infill ratio can reach 100%. However, printing time increases greatly.

Settings of print speed and temperatures enhance the qualitative and technological parameters of printing. The most significant parameter is print speed, which determines nozzle movements. As our model has many fine details, the set speed is 30 mm/sec to ensure printing accuracy. This is because high print speed affects its quality due to vibration efforts on the supporting frame of a printer and accelerated wear of drive elements.

The technology also provides for printing auxiliary model elements (not specified in geometry) considering the lack of possibility to form plastic mass in the air. This support is possible for both individual model elements (support type) and its platform (platform adhesion type). In this case, we select the Brim function to provide high-quality printing of model elements that are overhanging (the roof, domes). The programme creates additional supports for these elements.

After setting the required parameters to make a miniature, the file is sent to the printer with an automatically formed G-code, and the approximate print time and the amount of required material are determined.

Figure 5 presents a printed model of the Parochial Cathedral based on the suggested 3D modelling technology, the advantages of which are availability and low costs of produced models.

The methodology for creating the 3D model and printing the layout of the Parochial Cathedral has been carried out by specialists of the Innovative Centre for 3D Technologies of Design and Production, which operates on the basis of the Chair of Computer Technologies of the Ternopil Volodymyr Hnatyuk National Pedagogical University.

Some specific features of the developed model indicate possible further application of the methods to reconstruction activity in order to preserve the city and the state's cultural heritage.

4. Evaluation of the proposed methodology

Our research on improving the methodology for teaching the construction of 3D models of historic architectural objects was based on the proposed algorithm for performing architectural and spatial shaping in the process of reproducing a historic object.

In the process of teaching prospective IT specialists 3D technologies, we focused on the use of a comprehensive methodology for studying the graphical reconstruction of historical architectural objects. This methodology consists of the formation of skills in constructing a 3D model of an object based on design technologies according to image analysis using parallax evaluation of the data array of stereo pairs of images of the studied objects.

The proposed technique forms certain preliminary skills in students for the implementation of graphical reconstruction, which are important for their future professional activities. To substantiate



Figure 5: The printed miniature of the Parochial Cathedral of St Mary of Perpetual Assistance.

the effectiveness of the proposed technique, an experimental study was carried out. In the course of the study, methodological support was developed for conducting a cycle of laboratory studies.

Carrying out such a study helped to ascertain the effectiveness of the proposed methodology and create conditions for the introduction of positive achievements into the educational process.

A pedagogical experiment to test the effectiveness of the methodology for the formation of graphical reconstruction skills in prospective IT specialists covered 27 students of the "Professional Education (Computer Technologies)" specialty. The distribution of students for the experiment was as follows: the experimental group (EG) consisted of 14 students, and the control group (CG) consisted of 13 students. The research consisted of the introduction of the proposed methodology into the educational process of the EG, while the CG studied according to the traditional method.

All participants in the experiment were familiar with the purpose of the experiment and provided personal consent to participate. To test the effectiveness of the methodology, diagnostic tools were developed in the form of indicators, which were used to track a positive result in the formation of the skills of prospective IT specialists to carry out graphical reconstruction.

These indicators were: 1) knowledge about the technique of graphical reconstruction and the necessary tools; 2) knowledge of methods of geometric spatial design; 3) the ability to use software tools for building 3D models; 4) the ability to use image analysis technologies based on stereo pairs and parallax assessment; 5) knowledge of 3D printing technology.

These indicators made it possible to characterise four levels of skills of prospective IT specialists to carry out graphical reconstruction:

1) Low (characterised by low motivation to use graphical reconstruction technologies in professional activity and creative self-realisation; lack of geometric design skills; elementary theoretical and technological training in the use of specialised software for solving problems of graphical reconstruction and 3D printing; fragmented ability to analyse graphic information);
2) Medium (characterised by a limited interest in graphical reconstruction technologies and in the use of computer visualisation tools, partial skills to analyse graphic information and a situational desire to introduce software tools for the design of spatial objects in professional activities and the need for additional motivation, mediocre theoretical and technological training in the use of 3D printing);
3) Sufficient (characterised by significant motivation for the use of graphical reconstruction technologies and spatial modelling tools in professional activities, thorough training in the use of specialised software for solving typical tasks of graphical reconstruction and 3D printing, understanding of the process of analysing graphic information using arrays of digital data, readiness to reproduce typical models of graphical reconstruction);
4) High (characterised by a conscious and reasoned motivation for the use of graphical reconstruction technologies and spatial modelling tools in professional activities and for creative self-realisation, thorough training in the use of specialised software for solving creative problems of graphical reconstruction and 3D printing, the ability to evaluate graphic information and analyse digital data arrays corresponding to a graphical representation of a spatial object, formed by a sense of willingness to create their own models of graphical reconstruction).

Methods for determining achievements for the selected indicators were as follows:

1. Knowledge about the technique of graphical reconstruction and the necessary tools was tested with an appropriate set of test tasks.
2. Knowledge of methods of geometric spatial design was verified by tests.
3. The ability to use software tools for building 3D models was tested by executing a project.
4. The ability to use image analysis technologies based on stereo pairs and parallax assessments was tested by an individual task.
5. Knowledge of 3D printing technology was tested with an individual assignment.

During the experimental study, there were significant changes in the relationships between the knowledge levels of students in the control and experimental groups, which are reflected in table 2.

Analysis of the results of the experimental study showed that the quality of knowledge in the experimental group increased by 23.1%, and in the control group by only 14.3%. The average score increased accordingly: $\Delta\mu$ (EG) = 6.9; $\Delta\mu$ (CG) = 1.4. The dynamics of changes in the quality of knowledge of students from the EG and CG is presented in figure 6.

Consequently, conducting an experimental study using the proposed methodology proved its effectiveness in the educational process of prospective IT specialists. Thanks to the atypical approach to learning, a relaxed atmosphere is created, which contributes to better assimilation of the material.

5. Conclusions and future work

Graphical reconstruction of historical architectural objects is made possible by new technologies of 3D graphics, modelling, and design in specialised computer environments. The developed method of 3D technologies for graphical reconstruction is exemplified by the modelling of the Parochial Cathedral of St Mary of Perpetual Assistance from the 1950s.

Table 2
Dynamics of the level of knowledge of students.

Group	Experiment stage	Total number of students	Grade Point Average, μ	Knowledge level							
				High		Sufficient		Medium		Low	
				Number of students	%	Number of students	%	Number of students	%	Number of students	%
CG	I	14	78.7	4	28.6	5	35.7	4	28.6	1	7.1
	II		80.1	5	35.7	6	42.9	3	21.4	1	7.1
EG	I	13	75.3	3	23.1	5	38.5	3	23.1	2	15.3
	II		82.2	5	38.5	6	46.2	2	15.3	0	0

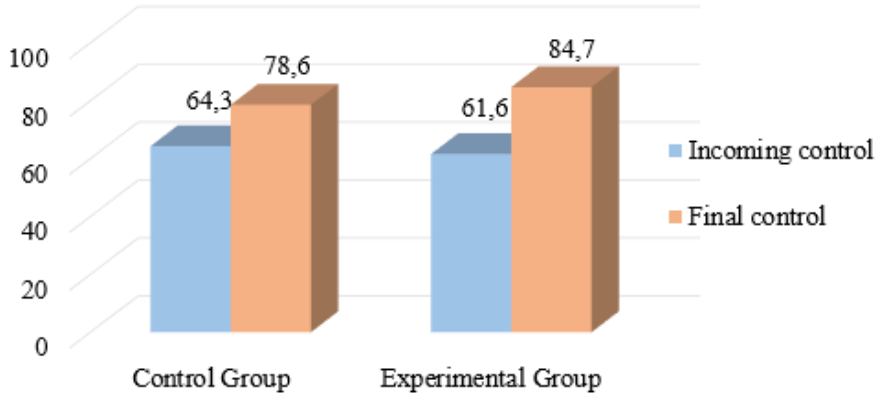


Figure 6: Dynamics of the quality of knowledge.

The proposed method of training in graphical 3D reconstruction is based on the principles of systematicity and consistency, accessibility, clarity, connection between theory and practice, and a combination of individual and collective learning. The stages of the proposed methodology (analysis, modelling, design, model printing) are based on a general methodology, taking into account individual specifics, depending on the tasks to be solved, the selected software, and the required degree of detail and realism.

Determination of the spatial configuration of objects provides for the restoration of the building according to the data indicated in archival sources, as well as based on determined parameters according to the comparison of descriptions and data on the construction technologies of cathedrals of that epoch.

A comprehensive method for the graphical reconstruction of historical architectural objects is proposed. This method consists of constructing a 3D model of an object, based on a combination of design techniques using modern 3D technologies, methods for analysing archival descriptive information and data from a set of images, and processing technology for a stereo pair data array of images of a destroyed cathedral.

3ds Max is selected to build a 3D model of the object to enhance high accuracy, speed, and granularity of fixing complex sets, providing efficient tools for working with bulk data that incorporate new achievements in information technologies.

Detailed analysis of images and determined sizes provides the basis for the 3ds Max model, which is

then edited by relevant tools to make it more realistic. The complex character of building the model implies its numerous fine details, their asymmetry, and location in different planes.

Creating a printed model of a 3D model requires its analysis and adaptation to 3D printing based on testing the model for the presence of open spaces in the polygonal mesh, defects in the geometry, and checking for compliance with the print materials. To build a printed model of the Cathedral, guided by criteria of convenience and a user-friendly interface, the Cura software environment is applied.

The presented teaching methodology provides for the formation of a system of theoretical and practical knowledge in students in the process of designing model buildings and structures using modern digital technologies of graphical 3D reconstruction.

To substantiate the effectiveness of the proposed technique, an experimental study was carried out, during which the developed methodological support was tested. An analysis of the results of the experimental study showed that the implementation of the proposed methodology contributes to the high-quality training of prospective IT specialists. Carrying out such research helped to create conditions for introducing positive achievements into the educational process.

Prospects for further research are defined in two directions:

1) Methodical: development of the training course "Graphical Reconstruction of Architectural Objects" and its introduction into the educational process of the "Professional Education (Digital Technologies)" specialty;
2) Technological: reconstruction of the Cathedral interior that would enable the creation of a virtual historical museum of the architectural monument. However, this problem requires auxiliary data on the Parochial Cathedral of St Mary of Perpetual Assistance and remains unsolved to date.

Declaration on Generative AI: The authors have not employed any Generative AI tools.

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A novel neuro-fuzzy approach for evaluating educational programme quality and institutional performance in higher education

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Abstract

This paper presents a novel methodology for evaluating the quality of educational programmes and institutional performance in higher education institutions using advanced artificial intelligence techniques, specifically the Adaptive Neuro-Fuzzy Inference System (ANFIS) and multi-layer neural networks. The primary objectives of the study were to address the challenges of subjectivity in self-assessment processes and proactively identify potential issues and deficiencies in educational activities prior to accreditation reviews. The proposed approach utilised student ratings on a four-level assessment scale as input data for the multi-layer neural network, while the criteria for assessing educational programme quality served as input variables for the ANFIS model. The underlying hypothesis was that students with higher academic performance would provide more objective assessments of the quality criteria. The results demonstrated that the multi-layer neural network exhibited superior predictive accuracy compared to the ANFIS model. This paper suggests that the proposed methodology can equip higher education leaders with high-quality forecasts to ascertain the calibre of educational services and pinpoint potential problems in advance of accreditation examinations. However, the authors acknowledge the necessity for further research with larger datasets to enhance the predictive capabilities of the models.

Keywords

educational programme evaluation, institutional performance assessment, neuro-fuzzy inference, ANFIS, artificial neural networks, higher education quality

CEUR-WS.org/Vol-3918/paper031.pdf

1. Introduction

The evaluation of educational quality is a complex and multifaceted endeavour, often involving the assessment of non-numerical characteristics that are challenging to formalise. While certain aspects of higher education institutions, such as the number of computers, students, or the area of educational premises, are quantifiable, the evaluation of educational programmes and institutional performance is typically conducted using qualitative criteria. In the context of self-assessment and accreditation processes, institutions and expert reviewers are required to assess compliance with established criteria using a four-level scale: A, B, E, and F.

Consequently, there is a pressing need for the development of methods that enable the quantitative description of processes and subjects related to the assessment of educational programme quality and institutional performance. The concept of educational quality is of particular significance, as it represents a comprehensive indicator that reflects both the outcomes of an educational institution and

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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

its alignment with societal needs and expectations in terms of individual competency development. The application of quantitative evaluation methods for educational programmes and institutional activities can empower higher education institutions to identify existing deficiencies and potential issues, providing an opportunity to address them proactively before accreditation examinations.

However, assessing the quality of educational programmes and institutional performance is complicated by the fact that the value of this indicator is influenced by numerous factors, potentially with an unknown nature of influence. Moreover, the "product" of education – a graduate of an educational institution – should be considered as a complex system. While various methods and algorithms exist for assessing the quality of educational activities, this study proposes a novel approach based on the neuro-fuzzy paradigm, leveraging the rapid advancements in artificial intelligence-based analytical systems. Among the most well-established and effective AI technologies are neural networks, which have demonstrated success in addressing a wide range of "fuzzy" tasks, such as prediction, classification, handwritten text recognition, language processing, image analysis [1, 2, 3], and often serve as the sole effective solution in scenarios where traditional technologies are inadequate. In this work, artificial neural networks are employed to tackle the challenge of evaluating the quality of educational programmes and institutional performance.

A prerequisite for accreditation is the compliance of educational programmes and institutional activities with legally established criteria. Specifically, the forms and methods of teaching should effectively contribute to the attainment of the stated objectives of the educational programme and the intended learning outcomes.

Given that educational programmes and institutional activities must adhere to the principles of student-centredness and academic freedom, the hypothesis of this study posits that a sample of current students and recent graduates can provide an adequate comprehensive assessment of the quality of educational programmes and institutional performance.

The intelligent processing of data using neural networks enables the generation of probabilistic forecasts of future accreditation examination results in higher education institutions, which can facilitate the improvement of measures aimed at enhancing educational programmes. These predictive insights can serve as informative and advisory resources for faculty and department leaders. Furthermore, educational programme coordinators can leverage these forecasts to plan activities and individualised work with educators to positively influence the predicted outcomes. The analysis of the obtained data can also reveal weaknesses in the educational process, providing opportunities for modernisation.

In light of these considerations, this article aims to substantiate, develop, and implement a mathematical model for the comprehensive assessment of educational programme quality and institutional performance based on neuro-fuzzy approaches.

1.1. Theoretical background

The assessment of educational activity quality based on well-defined criteria and methodologies is a crucial aspect of the accreditation process for educational programmes in Ukraine. During the preparation for accreditation and the compilation of materials for self-assessment, institutions often encounter challenges in determining the objectivity of their self-evaluation and identifying potential problems and shortcomings in their educational activities. To address this issue, there is an urgent need for mathematical tools that can assist higher education managers in evaluating the quality of the educational services they provide.

The shift in educational philosophy and practice has led to a heightened focus on student learning outcomes. The educational process should be results-oriented, emphasising what students actually know and can do. Consequently, student-centred learning has emerged as an approach in which students influence the content, activities, materials, and pace of their learning, placing them at the heart of the learning process [4].

European Union initiatives emphasise the importance of increasing the efficiency, international attractiveness, and competitiveness of higher education institutions. Wächter et al. [5] examines various approaches to quality, quality assurance, and ratings, analysing recent research and providing

recommendations and policy options for parliament from a comparative perspective.

The challenge of identifying a set of effective indicators that are easily measurable and applicable to diverse institutions, from large public universities to small regional private colleges, and from university programmes to alternative programmes, is also relevant in the United States [6].

Cherniak et al. [7] explored the possibility of assessing the quality of qualimetry objects using a graph-analytical method, applying the principle of determining the area and volume under curved surfaces, both in the plane and in space, created by combining estimates of individual quality indicators on a dimensionless scale. The research demonstrates that mathematical dependencies are typically nonlinear, and their investigation involves the development of universal methods applicable to qualimetry objects, regardless of their nature, complexity, or importance. By representing unit quality indicators on a single (dimensionless) rating scale, the authors propose determining a single comprehensive quality indicator for a qualimetry object using the integration method, which takes into account the evaluation of unit quality indicators.

Parvu and Ipate [8] propose a mathematical model based on a set of indicators adapted to the globally recognised classification structure of intellectual capital, namely the external structure, internal structure, and employee competence. The Rompedet method, an original product of the Romanian school of management [9], is employed as a mathematical calculation tool.

When assessing the quality of education, we encounter a vast array of criteria, each potentially consisting of numerous sub-criteria. Consequently, the task of evaluating educational quality in its mathematical formulation is inherently multi-criteria. Problem situations modelled and described by linear models that depend on multiple factors play a significant role, and solving multi-criteria decision-making problems often involves solving multi-criteria linear programming problems, also known as vector optimisation problems.

Considering these challenges, mathematical models of integrated quality assessment using methods based on the convolution of criteria were also of interest for this study. Models and methods of multi-criteria optimisation are discussed in [10], particularly the method of additive convolution of criteria and the method of multiplicative and minimax convolution of criteria. The method of multiplicative convolution of partial criteria to a single generalised indicator, which utilises the maximum (minimum) values of partial criteria as a normalised divisor, is considered in [11]. Chervak [12] employs one of the methods for solving the Paretian multi-criteria optimisation problem as a mathematical tool in the decision-making process. To organise selection problems on the same admissible set of alternatives, the concept of a super criterion for any criterion is introduced; if one criterion is a super criterion of another on a given set, the latter is a sub-criterion of the former. The solution of the multi-criteria selection problem by Paretian convolution is shown to be reducible to the solution of scalar or lexicographic optimisation problems.

The theory of artificial neural networks and deep learning models is explored in fundamental works [13, 14, 15], while system design based on the neuro-fuzzy approach is discussed in [16, 17, 18, 19, 20].

Lesinski et al. [21] consider the use of neural networks to classify the status of higher education graduates based on selected academic, demographic, and other indicators. A multi-layer neural network with feedback is employed as a model, trained on over 5,000 records from entrance exams and university databases. The nine input variables consisted of categorical and numerical data containing information about high school education, test results, high school teacher assessments, parental assessments, and more. Based on these inputs, the multi-layer neural network predicted the success of university entrants, achieving a classification accuracy exceeding 95%. Black et al. [4], examining the relationship between quality and high school student success in college, found no convincing evidence that exposure characteristics of high school diminish over time in teaching students.

To address the issue of determining the quality of educational training, Mahapatra and Khan [22] developed the EduQUAL methodology and proposed an integrative approach using neural networks to assess educational quality. Four neural network models based on a feedback algorithm are used to predict educational quality for different stakeholders, with the P-E Gap model identified as the best model for all stakeholders.

The need to introduce neural network technology in educational courses is highlighted by Semerikov

et al. [23]. Educational neural networks are often used for forecasting purposes. For example, students must choose courses of interest for the upcoming semester, but due to limitations such as insufficient resources and the overhead of offering multiple courses, some universities may not be able to teach all courses selected by students. Universities need to know each student's course requirements for optimal course planning each semester. Kardan et al. [24] used a neural network to model student choice behaviour and apply the resulting function to predict the final enrolment of students for each course, demonstrating high prediction accuracy based on experimental data. Arsad et al. [25], Osadchyi et al. [26], and Okubo et al. [27] prove that the use of neural networks in predicting educational processes allows obtaining results with significantly higher accuracy and in less time. According to Abu Naser et al. [28], an artificial neural network can correctly predict the success of more than 80% of future students.

Chaban and Kukhtiak [29] analyse the problem of the social system consisting of many higher education students and teachers to create effective "teacher-student" learning pairs, using elements of artificial intelligence theory based on artificial neural networks to form these learning pairs. Okubo et al. [30] propose the use of a recurrent neural network (RNN) to predict students' final grades using journal data stored in educational systems.

Liu et al. [31] propose a method for assessing the quality of postgraduate education preparation based on the neural network backpropagation algorithm and stress testing. This method creates a publicly available list of indicators consisting of 19 criteria in 4 groups: attitudes towards teaching, teaching content, teaching approach, and key teacher characteristics. After the neural network algorithm determines the optimal parameters of the evaluation model, a sensitivity test identifies indicators that significantly impact educational quality. Additionally, scenario analysis is used to study the impact of educational quality in predefined situations, providing theoretical and empirical support for assessing the quality of postgraduate teaching, improving educational quality, and fostering teachers' professional growth.

Educational institutions continuously strive to improve their services, aiming to have the best teaching staff, enhance teaching quality, and boost students' academic success. Understanding the factors influencing student learning can help universities and learning centres adapt their curricula and teaching methods to meet students' needs. One of the first measures taken by educational institutions in response to the COVID-19 pandemic was the creation of virtual learning environments [32]. To understand the factors influencing the university learning process in virtual learning environments, Rivas et al. [33] applied several automatic learning methods, including tree-like models and various types of artificial neural networks, to publicly available datasets.

The availability of educational data supported by learning platforms [34] provides opportunities to study student behaviour and solve problems in higher education, optimise the educational environment, and ensure decision-making using artificial neural networks [35].

Cader [36] uses a deep neural network to assess students' acquisition of knowledge and skills, noting that the relatively small amount of available assessment data required for neural network training is an obstacle to the application of the method in teaching. A new data augmentation method – asynchronous data augmentation through pre-categorisation – is proposed to address this problem, enabling neural network training even for small datasets.

Do and Chen [37] present a neuro-fuzzy classifier that uses the results of previous exams and other related factors as input variables to classify students based on their expected learning outcomes. The results showed that the proposed approach achieved high accuracy compared to other known classification approaches, such as Naive Bayes and neural networks.

Fazlollahtabar and Mahdavi [38] proposed a neuro-fuzzy approach based on evolutionary techniques to obtain the optimal learning pathway for both teachers and students. The neuro-fuzzy approach provides recommendations to teachers for making pedagogical decisions based on students' learning styles, while the neural network approach is used for students to create personalised curriculum profiles based on their individual needs in a fuzzy environment.

Taylan and Karagözoğlu [39] use a systematic approach to designing a fuzzy inference system based on a class of neural networks to assess student achievement. The developed method uses a fuzzy system,

supplemented by neural networks, to enhance characteristics such as flexibility, speed, and adaptability, referred to as the adaptive neuro-fuzzy inference system (ANFIS). The results of the ANFIS model are as reliable as statistical methods but encourage a more natural way of interpreting student learning outcomes.

In comparison with these works, this study fills a gap in the methods of comprehensive assessment of educational programme quality and institutional performance based on a neuro-fuzzy approach.

1.2. Methods

This study employed methods of mathematical modelling and computational experimentation based on the statistical processing of data assessments of educational programme quality and institutional performance. The essence of the mathematical modelling methodology is to replace the original object with its mathematical model and study it using computer technology. The processing, analysis, and interpretation of calculation results were carried out through constant comparison with the results of statistical processing of expert estimates. Throughout the research, refinements were made, the mathematical model was revised, and the cycle of the computational experiment was repeated.

The methodology for assessing the quality of the curriculum and educational activities is built using artificial intelligence methods and tools, implemented in the Fuzzy Logic Toolbox of the MATLAB system in the form of an adaptive neuro-fuzzy output (ANFIS).

A fuzzy inference system can be represented as a neuro-fuzzy network – a special type of direct signal propagation neural network, or ANFIS model. The architecture of a neuro-fuzzy network is isomorphic to a fuzzy knowledge base. Neuro-fuzzy networks use differentiated implementations of triangular norms (multiplication and probabilistic OR) and smooth membership functions. This enables the use of fast training algorithms for neural networks based on the backpropagation method to tune neuro-fuzzy networks.

ANFIS implements the Sugeno fuzzy inference system through a five-layer feed-forward neural network. The purpose of each network layer is as follows:

- First layer – terms of input variables;
- Second layer – antecedents (parcels) of fuzzy rules;
- Third layer – normalisation of the degree of implementation of the rules;
- Fourth layer – conclusion of the rules;
- Fifth layer – aggregation of the result obtained according to different rules.

The network inputs are not allocated to a separate layer. Figure 1 shows an ANFIS network with two input variables (x_1 and x_2) and four fuzzy rules. Three terms are used for the linguistic evaluation of the input variable, and two terms for the variable.

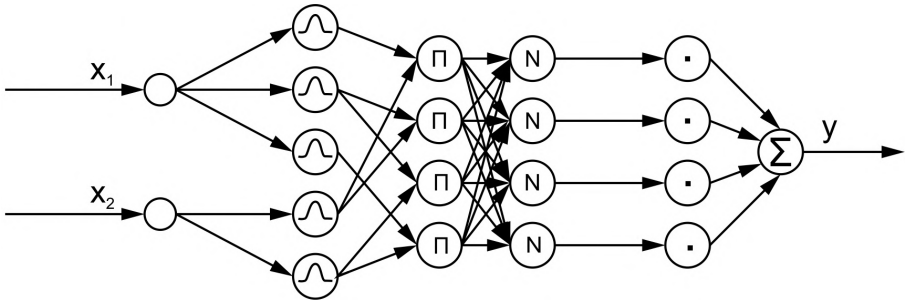


Figure 1: An example of an ANFIS network.

We will use the following notation:

- $x_1, x_2, ..., x_n$ – network inputs;
- y – network output;

- R_r : if $x_1 = a_{1,r}, ..., x_n = a_{n,r}$ it $y = b_{0,r} + b_{1,r}x_1 + ... + b_{n,r}x_n$ is a fuzzy rule with a serial number r;
- m – number of rules $\overline{r = 1, m}$,
- $a_{i,r}$ – fuzzy term with a membership function $\mu_r(x_i)$ used for linguistic evaluation of a variable x_i in the r-th rule ($r = \overline{1, m}, i = \overline{1, n}$);
- $b_{q,r}$ are the conclusion coefficients of the r-th rule ($r = \overline{1, m}, q = \overline{0, n}$).

The ANFIS network operates as follows.

Layer 1. Each node of the first layer represents one term with a bell membership function. The network inputs are connected only to their terms. The number of nodes in the first layer is equal to the sum of the cardinalities of the term set of input variables. The degree of belonging of the value of the input variable to the corresponding fuzzy term is fed to the output of the node:

$$\mu_r(x_i) = \frac{1}{1 + \left|\frac{x_i - c}{a}\right|^{2b}}, \tag{1}$$

where a, b and c are membership function parameters that can be tuned.

Layer 2. The number of nodes in the second layer is m. Each node of this layer corresponds to one fuzzy rule. The node of the second layer is connected to the nodes of the first layer, which form the antecedents of the corresponding rule. Therefore, each node of the second layer can receive from 1 to n signals. The output of the node is the degree of execution of the rule, calculated as the product of the input signals. Let us denote the outputs of the nodes of this layer as $\tau_r, r = \overline{1, m}$.

Layer 3. The number of nodes in the third layer is also m. Each node of this layer calculates the relative level of execution of the fuzzy rule according to the formula:

$$\tau_r^* = \frac{\tau_r}{\sum\limits_{j=1}^{m} \tau_j}. \tag{2}$$

Layer 4. The number of nodes in the fourth layer is also m. Each node is connected to one node of the third layer, as well as to all inputs of the network (figure 1 connections to the inputs are not shown). The node of the fourth layer calculates the contribution of one fuzzy rule to the network output by the formula:

$$y_r = \tau_r^*(b_{0,r} + b_{1,r}x_1 + ... + b_{n,r}x_n). \tag{3}$$

Layer 5. A single node of this layer sums up the contributions of all rules:

$$y = y_1 + ... + y_r + ... + y_m. \tag{4}$$

Typical neural network training procedures can be applied to tune an ANFIS network, as it uses only differentiated features. A combination of gradient descent as a backpropagation algorithm and the least-squares method is commonly used. The error backpropagation algorithm regulates the parameters of rule antecedents, i.e., membership functions. The least-squares method evaluates the rule inference coefficients since they are linearly related to the network output.

Each iteration of the tuning procedure is performed in two steps.

In the first stage, a training sample is fed to the inputs, and based on the discrepancy between the desired and actual behaviour of the network, the optimal parameters of the nodes of the fourth layer are determined using the least-squares method.

In the second stage, the residual mismatch is transmitted from the network output to the inputs, and the parameters of the nodes of the first layer are modified by the backpropagation of the error. At the same time, the rule inference coefficients found at the previous stage do not change. The iterative tuning

procedure continues as long as the mismatch exceeds a predetermined value. To tune the membership functions, in addition to the error backpropagation method, other optimisation algorithms can be used, such as the Levenberg-Marquardt method.

The ANFIS editor in MATLAB allows the automatic synthesis of a neuro-fuzzy network from experimental data. In this case, the accessories of the synthesised systems are tuned (trained) in such a way as to minimise the deviations between the results of fuzzy modelling and experimental data. The ANFIS editor is loaded using the anfisedit command.

The ANFIS editor contains 3 top menus – File, Edit and View, a visualisation area, ANFIS properties area, data loading area, source fuzzy inference system generation area, training area, testing area, current information output area, as well as Help and Close buttons, which allow calling the help window and closing the ANFIS editor, respectively.

Participants in the experiment were 22 full-time master's students and 32 graduates of higher education institutions of the previous term studying the same specialities – a total of 54 people. This number of respondents is due to the number of indicators of quality criteria because the data format of the artificial network in MATLAB supports square matrices, in this case, 54x54. Before the accreditation examination, students were offered questionnaires with a proposal to assess the quality of the educational programme and educational activities of the speciality on an assessment scale covering four levels: F, E, B, A. Student assessments were used to form the vector of artificial neural network inputs. After the accreditation examination, the expert assessments were used to check the quality of the prediction of the artificial neural network.

The experience of European countries demonstrates the expediency of involving students in accreditation examinations. For example, the Polish Accreditation Commission consists of 80–90 members appointed by the Minister of Science and Higher Education among the candidates nominated by the Senates of higher education institutions, the conferences of rectors of scientific schools and universities in Poland, and the Parliament of Students of Poland (the President of the Student Parliament is a member of the Polish Accreditation Commission). In Slovakia, the Academic Ranking and Rating Agency is a civic association founded in 2004 on the initiative of former student leaders and academics. The Slovenian Quality Assurance Agency for Higher Education SQAA-NAKVIS appoints at least three members of each expert group, of which at least one foreign expert, an expert in the field of quality assessment of higher education, and one representative from among students [40].

To ensure the representativeness of the sample, the study of its design was carried out based on randomisation. The decision on the statistical deviation of the null hypothesis regarding the differences between the averages was also associated with the procedure of random sampling.

The rating scale covers four levels of compliance with the requirements of the legislation (F, E, B, A) [41]. The legislation also establishes 10 criteria for assessing the quality of the educational programme [41]:

1) Design and objectives of the educational programme (4);
2) Structure and content of the educational programme (9);
3) Access to the educational programme and recognition of learning outcomes (4);
4) Teaching and learning according to the educational programme (5);
5) Control measures, evaluation of applicants for higher education and academic integrity (4);
6) Human resources (6);
7) Educational environment and material resources (6);
8) Internal quality assurance of the educational programme (7);
9) Transparency and publicity (3);
10) Learning through research (6).

In turn, each of these criteria has from 3 to 9 indicators (the number is indicated in parentheses). Together, all 10 criteria contain 54 indicators.

2. Results

In the first stage of the study, data on the results of the assessment of students and graduates of higher education regarding educational programmes and educational activities for each criterion were collected and statistically processed.

In the second stage, a computational experiment was performed. The cycle of the computational experiment was carried out in several stages:

1) Choice of approximation and mathematical formulation of the problem (construction of a mathematical model of the phenomenon under study);
2) Development of a computational algorithm for solving the problem;
3) Implementation of the algorithm in the form of a PC program;
4) Calculations on the PC;
5) Processing, analysis and interpretation of calculation results, comparison with the results of statistical processing of expert estimates and, if necessary, refinement or revision of the mathematical model, i.e., return to the first stage and repeat the cycle of the computational experiment.

Assessing the quality of the curriculum and learning activities is complicated by the fact that each of the 10 criteria, in turn, consists of several indicators (3-9) and is due to many factors, possibly with an unknown nature of influence, which is also non-numerical. To assess the quality of the curriculum and training activities, a two-tier system based on the ANFIS package and artificial neural networks is proposed to predict assessment scores.

The ANFIS hybrid system is a combination of the Sugeno neuro-fuzzy inference method with the ability to train a five-layer artificial neural network (ANN) of direct propagation with a single output and multiple inputs, which are fuzzy linguistic variables. As input variables of the ANFIS system, we use the criteria for evaluating the quality of the educational programme of 10 groups of factors $V_i(i = 1, ..., 10)$.

The output variable of the ANFIS system is a numerical assessment of the quality of the curriculum and training activities and is defined as a function $y = f(V_1, V_2, V_3, V_4, V_5, V_6, V_7, V_8, V_9, V_10)$.

Layer 1 of the ANFIS system for the linguistic evaluation of input parameters uses the term set of all possible values of the linguistic variable. $A_{Vi} = \{\text{“}F\text{”}, \text{“}E\text{”}, \text{“}B\text{”}, \text{“}A\text{”}\}$. In symbolic form we write: $A_{Vi} = \{F < i >, E < i >, B < i >, A < i >\}$. The term set of the original linguistic variable y is the set of values of quality assessments of the curriculum and educational activities: $T_y = \{F, E, B, A\}$. The outputs of the nodes of layer 1 are the values of the membership functions at specific values of the input variables.

Layer 2 is non-adaptive and defines the preconditions of fuzzy production rules. Production rules – a form of representation of human knowledge in the form of a sentence type – if (condition), then (action). The rules provide a formal way to present recommendations, guidance, or strategies. They are ideal in cases where the knowledge of the subject area arises from the empirical associations accumulated during the work on solving problems in a particular field.

Each node of this layer is connected to those nodes of layer 1, which form the prerequisites of the corresponding rule. To solve this problem, four fuzzy production rules are formulated: $P = \{p_1, p_2, p_3, p_4\}$, because according to the features of the ANFIS network, the number of network rules must correspond to the dimension of the term set of the source variable y.

Nodes perform a fuzzy logical operation “I” (min). The outputs of the nodes of this layer are the degree of truth (fulfilment) of the preconditions of each of the four fuzzy production rules, which are calculated by the formulas:

$$\begin{cases} w_1 = \min(\mu_{F1}(V_1), \mu_{F2}(V_2), \mu_{F3}(V_3), \mu_{F4}(V_4)) \\ w_2 = \min(\mu_{E1}(V_1), \mu_{E2}(V_2), \mu_{E3}(V_3), \mu_{E4}(V_4)) \\ w_3 = \min(\mu_{B1}(V_1), \mu_{B2}(V_2), \mu_{B3}(V_3), \mu_{B4}(V_4)) \\ w_4 = \min(\mu_{A1}(V_1), \mu_{A2}(V_2), \mu_{A3}(V_3), \mu_{A4}(V_4)) \end{cases}. \quad (5)$$

Layer 3 normalises the degree of implementation of each of the fuzzy production rules (calculation of the relative degree of implementation of the rules) as follows:

$$\overline{w}_h = \frac{w_h}{\sum_{i=1}^{h} w_i}, \tag{6}$$

where $h = 1, ..., 4$ is the production rule number. Layer 4 calculates the contribution of each fuzzy production rule to the output of the network according to the formula.

$$y_h(v, V) = \overline{w}_h(v_h^{(0)} + v_h^{(1)}V_1 + v_h^{(2)}V_2 + v_h^{(3)}V_3 + v_h^{(4)}V_4 + v_h^{(5)}V_5), \tag{7}$$

where $v_h^{(0)}$ – coefficients of the initial function ($i = 0, ..., 5$).

Layer 5 summarises the contributions of all the rules:

$$y = \sum_{i=1}^{4} y_i. \tag{8}$$

Training of the ANFIS network was carried out for 24 epochs by a hybrid method. During training, the type of membership functions, the type of initial function, and their coefficients are selected. As a result of training a fuzzy network for four rules, Gaussian functions were adopted as membership functions, and a linear function was adopted as the initial function. As a result of training, membership functions and their coefficients were also obtained.

To assess each of the 10 groups of factors that affect the quality of the curriculum and educational activities by the evaluation criteria, 10 modules are used, which are implemented using artificial neural networks. Thus, it is necessary to design neural networks, a mathematical model of a comprehensive assessment of the quality of the educational program and educational activities based on the methods of the neuro-fuzzy approach. For this purpose, the Neural Network Toolbox was used. To form neural networks, it is necessary to determine their topology, learning mechanism, and testing procedure. Also, the training of an artificial neural network requires input data – a sample of answers of students and graduates with reliable quality indicators, determined based on these criteria.

A standard L-layer feedforward neural network consists of a layer of input nodes (we will stick to the position that it is not contained in the network as an independent layer), $(L - 1)$ hidden layers, and an output layer that is connected in series in the forward direction and does not contain a connection between elements within a layer and feedback between layers. The most popular class of multilayer feed-forward networks is formed by multilayer perceptrons, where each computational element uses a limit or sigmoidal activation function. A multilayer perceptron can form arbitrarily complex decision limits and implement arbitrary Boolean functions. The development of a backpropagation algorithm for determining weights in a multilayer perceptron has made these networks the most popular among researchers and users of neural networks. The vast majority of programs involve the use of such multilayer perceptrons. Networks consisting of successive layers of neurons are more commonly used. Although any network without feedback can be represented as successive layers, the presence of many neurons in each layer can significantly speed up calculations using matrix accelerators.

The popularity of perceptrons is due to a wide range of available tasks that can be solved with their help. In the general case, they solve the problem of approximating multidimensional functions, that is, constructing a multidimensional mapping $F : x \Rightarrow y$ that generalizes a given set of parameters $\{x^\alpha \Rightarrow y^\alpha\}$.

Depending on the type of output variables (the type of input variables is not critical), the approximation of functions can take the form of classification (discrete set of initial values), or regression (continuous initial values).

Many practical problems of pattern recognition, noise filtering, time series prediction, etc. come down to basic settings. The reason for the popularity of perceptrons is that, for their range of tasks,

they are, firstly, universal, and secondly, they are efficient in terms of the computational complexity of devices.

As a result of the development of neurocomputing, a large number of efficient models of neural networks have been created, focused on solving various problems. Due to this, artificial neural networks are successfully used to solve a wide class of practical problems. Therefore, when solving a specific problem, it is necessary to solve the issue of choosing the most appropriate neural network model, its parameters, and the training method.

Typically, a network consists of many sensor elements (input nodes or source nodes) that form an input layer; one or more hidden layers of computational neurons, and one output layer of neurons. The input signal propagates through the network in a forward direction from layer to layer. Such networks are usually called multilayer perceptrons. They are a generalization of a single layer perceptron.

Multilayer perceptrons are successfully used to solve various problems. At the same time, supervised learning is performed using such a popular algorithm as the error back-propagation algorithm. This method consists of error correction (error-correction learning rule). It can be thought of as a generalization of the equally popular adaptive filtering algorithm, the mean squared error minimization (LMS) algorithm.

Multilayer perceptrons have three characteristic features.

1. Each neuron of the network has a non-linear activation function. It should be noted that this non-linear function is smooth (that is, differentiated everywhere), in contrast to the hard threshold function used in the Rosenblatt perceptron. The most popular form of a function that satisfies this requirement is the sigmoidal nonlinearity, defined by the logistic function

$$y_i = \frac{1}{1 + \exp(-v_j)}, \tag{9}$$

   where v_j is the induced local field (i.e., the weighted sum of all synaptic inputs plus the limit value) of neuron j; y_j is the output of the neuron. The presence of non-linearity plays a very important role, since otherwise the "input-output" mapping of the network can be reduced to a conventional single-layer perceptron. Moreover, the use of the logistic function is biologically motivated, since it takes into account the recovery phase of a real neuron.
2. The network contains one or more layers of hidden neurons that are not part of the input or output of the network. These neurons allow the network to learn how to solve complex problems by sequentially extracting the most important features of the input image (vector).

The network has a high degree of connectivity (connectivity), implemented using synaptic connections. Changing the level of network connectivity requires changing the plurality of synaptic connections or their weights.

The combination of all these properties, along with learning-by-doing, provides the computational power of a multilayer perceptron. However, these same qualities are the reason for the incompleteness of modern knowledge about the behaviour of such networks. First, the distributed form of nonlinearity and the high connectivity of the network significantly complicate the theoretical analysis of a multilayer perceptron. Second, the presence of hidden neurons makes the learning process more difficult to visualise. It is in the learning process that it is necessary to determine which signs of the input signal should be given by hidden neurons. Then the learning process becomes even more difficult, since the search must be performed in a wide range of possible functions, and the choice must be made among alternative representations of the input images.

The emergence of the backpropagation algorithm was a landmark event in the development of neural networks, since it implements a computationally efficient method for training a multilayer perceptron. The backpropagation algorithm does not offer a truly optimal solution to all potential problems, but it is most effective in learning multilayer machines.

An artificial neural network for the analysis of indicators of the quality of the educational program and educational activities will have the number of input neurons (according to the number of indicators for all criteria) 54; output neurons – 54. Input signals were determined based on students' assessments

of each indicator of this quality criterion, while the scale F, E, B, A were translated into numerical 1; 2; 3; 4 respectively. Part of the data is given in table 1.

Table 1
Input signals (T) based on students' assessments of quality criteria.

Indicators of quality criteria	Student grades								
	1	2	3	4	5	6	7	...	54
1	3	4	3	3	4	3	4	...	4
2	4	3	3	3	4	3	3	...	4
3	3	3	4	3	4	4	3	...	4
...	...	...	...	...	...	...	...	...	...
54	4	3	3	3	4	3	3	...	4

It is important that the neural network can predict expert assessments if student and graduate assessments are to be ranked in ascending order based on the determination of the grade point average. According to the hypothesis, we assume that students with higher academic performance are better acquainted with the goals, structure, and content of the educational program, the process and characteristics of teaching and learning according to the educational program, control measures, assessment system, and all other aspects of educational activities. assessments of the quality of the educational program and educational activities will be more objective.

The Neural Network Toolbox application package Matlab Mathematical Modeling Environment (version R2014a) was used in the work. After starting the Matlab system, enter the nntool command on the command line, which opens the window for entering data and creating a neural network (Neural Network / Data Manager) (figure 2).

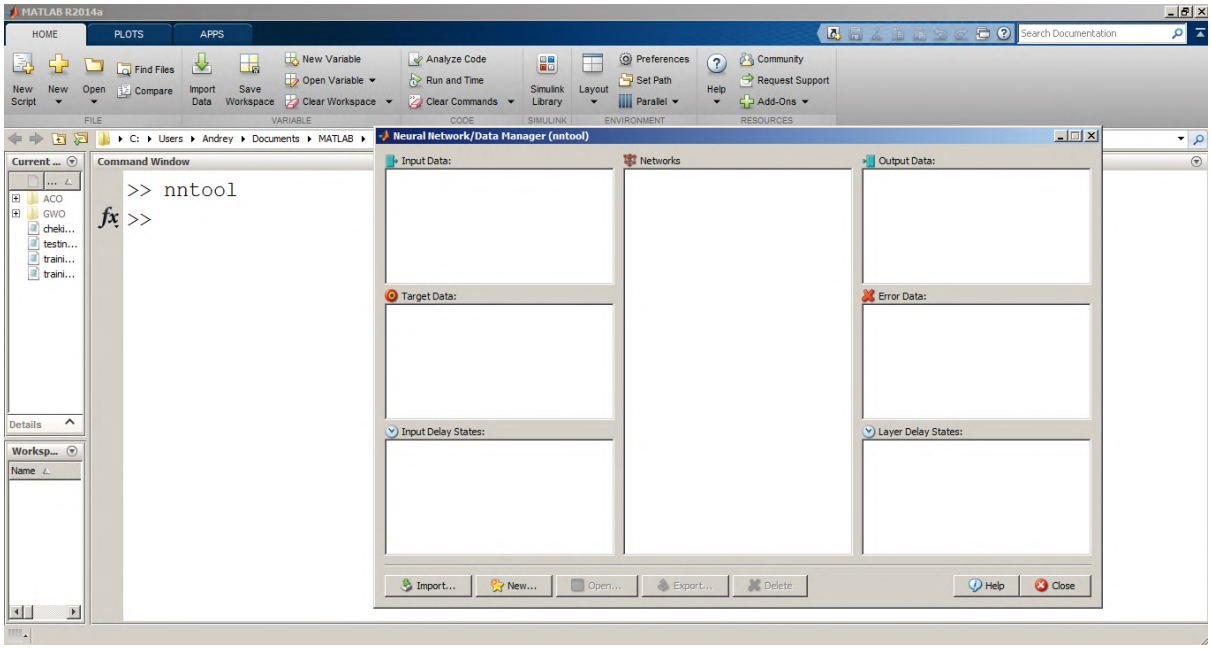


Figure 2: Data entry and neural network creation windows.

After starting the MATLAB system, you need to enter the tool command on the command line, which will open the window for entering data and creating a neural network (Neural Network / Data Manager). Clicking the New button opens the Create Network or Data window. After selecting the Data tab in the Name field you must enter a new name of the input data "P", and in the Value field the values of the input data, in which the numbers 1-54 are indicators of quality criteria, and 55-108 – students' and graduates' indicators quality criteria.

To create a new network, we chose New, to view the data you need to select Import. The data is

contained in the P.mat file. This file is a matrix of two lines, in which the numbers 1-54 are indicators of quality criteria, and 55-108 – are the evaluation of students and graduates on the indicators of quality criteria. Its contents are stored in the P.txt file.

The next step is to import the data (figure 3).

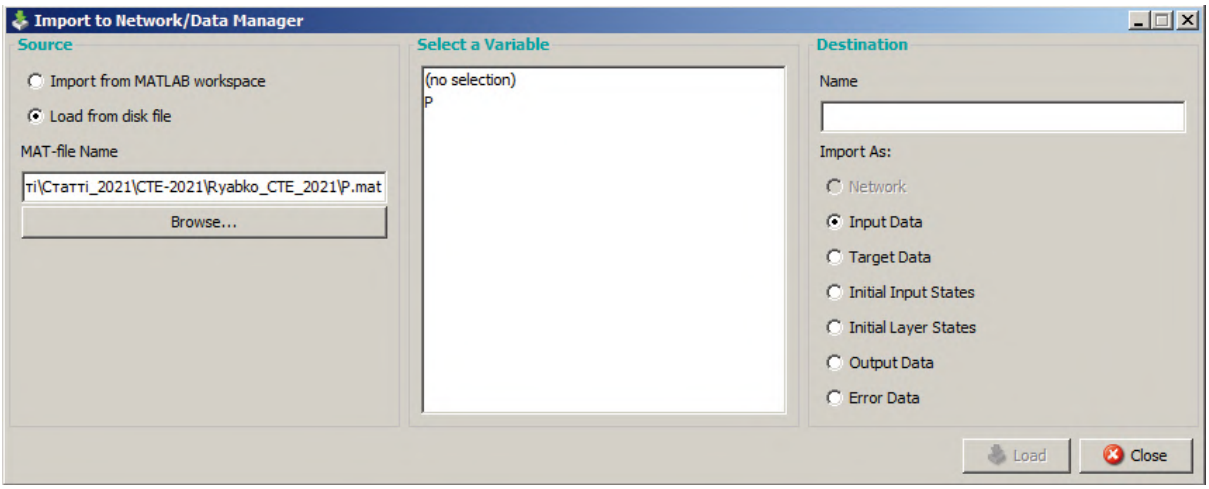


Figure 3: Importing data.

The next step was to create data ("T") – goals, which are an array of size 54x54, which contains information about the grades given by the participants of the experiment – full-time master's students (22 people) and graduates of higher education institutions there are specialties (32 people) – a total of 54 people. This number of respondents is due to the number of indicators of quality criteria because the data format of the artificial network in Matlab supports square matrices, in this case, 54x54. The data is stored in a T.mat file. Its contents can be viewed using a text editor.

We import data in the same way as for the array P.

In the next step, a neural network was created (figure 4). An artificial neural network for the analysis of indicators of the quality of the educational program and educational activities will have the number of input neurons (according to the number of indicators for all criteria) 54; output neurons – 54. Input signals were determined based on students' assessments for each indicator of this quality criterion, while the scales F, E, B, A were converted to numerical 1; 2; 3; 4 respectively.

The configuration of the neural network of direct propagation is chosen based on a heuristic rule: the number of neurons of the hidden layer is equal to half of the total number of input and output neurons. The artificial neural network for the analysis of quality indicators of the educational program and educational activity will have the number of input neurons 2 (according to the dimensionality of the data – indicators of quality criteria and student evaluation); source neurons 54, therefore, the number of hidden neurons is 28. The View button allows you to view the network structure (figure 5).

In our case, 2 is the number of input neurons, which is known to be selected based on the dimension of the input data (1 – indicators of quality criteria; 2 – student assessments). Output neurons – 54. The configuration of the neural network of direct propagation (feed-forward backdrop) is chosen based on the heuristic rule: the number of neurons in the hidden layer is equal to half the total number of input and output neurons, so the hidden layer has 28 neurons.

The next stage is network training and coaching. Double-clicking with the left mouse button on the created neural network network1 in the window of the Neural Network / Data Manager opens a window with the network.

The View tab presents the neural network itself. Go to the Reinitialize Weights tab, where the Input Ranges column selects the P input from the Get from the input list. Then press the Set Input Ranges and Initialize Weights buttons in succession allowing us to initialize the scales needed to initialize the entire network.

The next step is network learning.

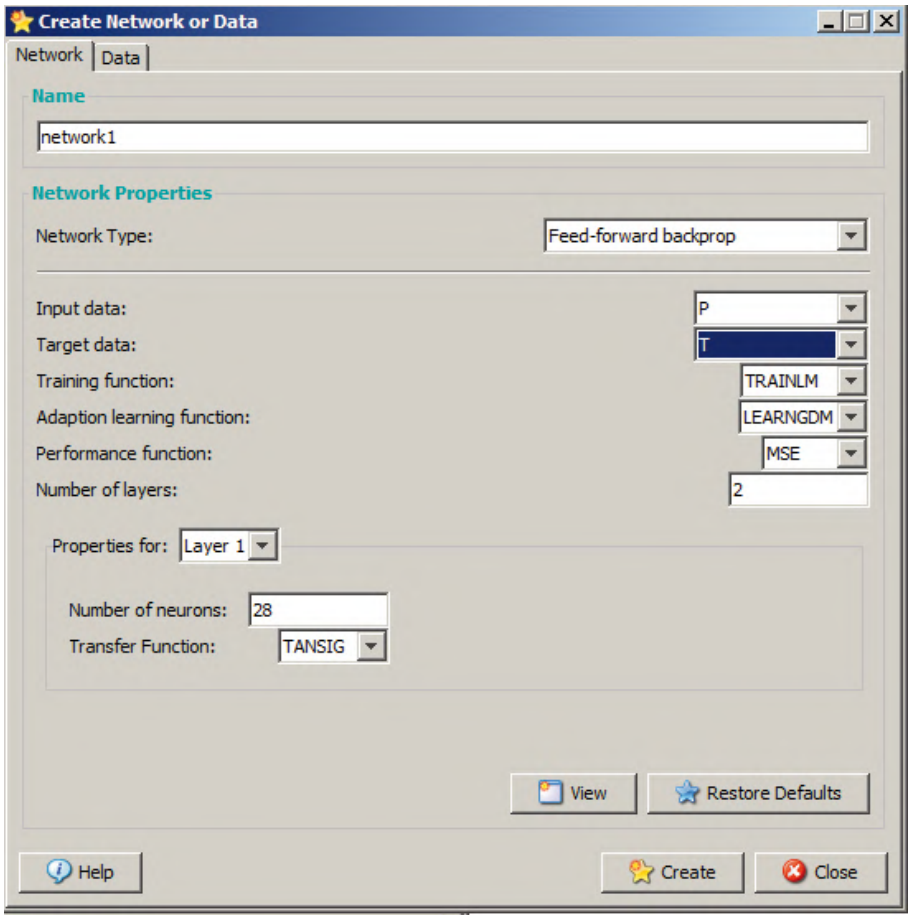


Figure 4: Creating a neural network.

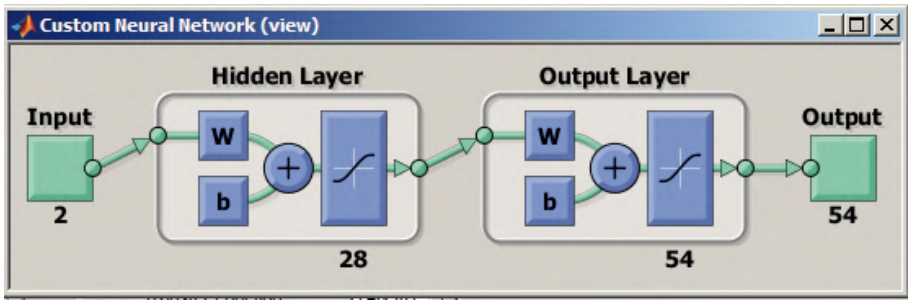


Figure 5: The structure of the neural network.

Learning the backpropagation method involves two passes through all layers of the network: forward and backward. In a forward pass, the image (incoming vector) is fed to the sensor nodes of the network, after which it propagates through the network from layer to layer. As a result, a set of output signals is generated, which is the actual response of the network to a given input image. In forward traversal, all synaptic weights of the network are fixed. In a backward pass, all synaptic weights are adjusted according to the error correction rule, namely: the actual output of the network is subtracted from the desired (target) response, resulting in an error signal. This signal subsequently propagates through the network in the opposite direction of the synaptic connections. Hence the name – backpropagation algorithm. The synaptic weights are tuned to bring the network output as close as possible to the desired statistical meaning. The back-propagation algorithm is sometimes referred to as the simplified back-propagation algorithm. The learning process using this algorithm is called back-propagation learning.

Going to the Train tab opens a learning window in which P and T are selected instead of input data and targets, respectively (figure 6). On the right of the Training Results column, you need to change the name of the Outputs and Errors to O and E, respectively. Then pressing the Train Network button will start network training, the process of which can be observed in the Neural Network Training window. You can close the window after graduation.

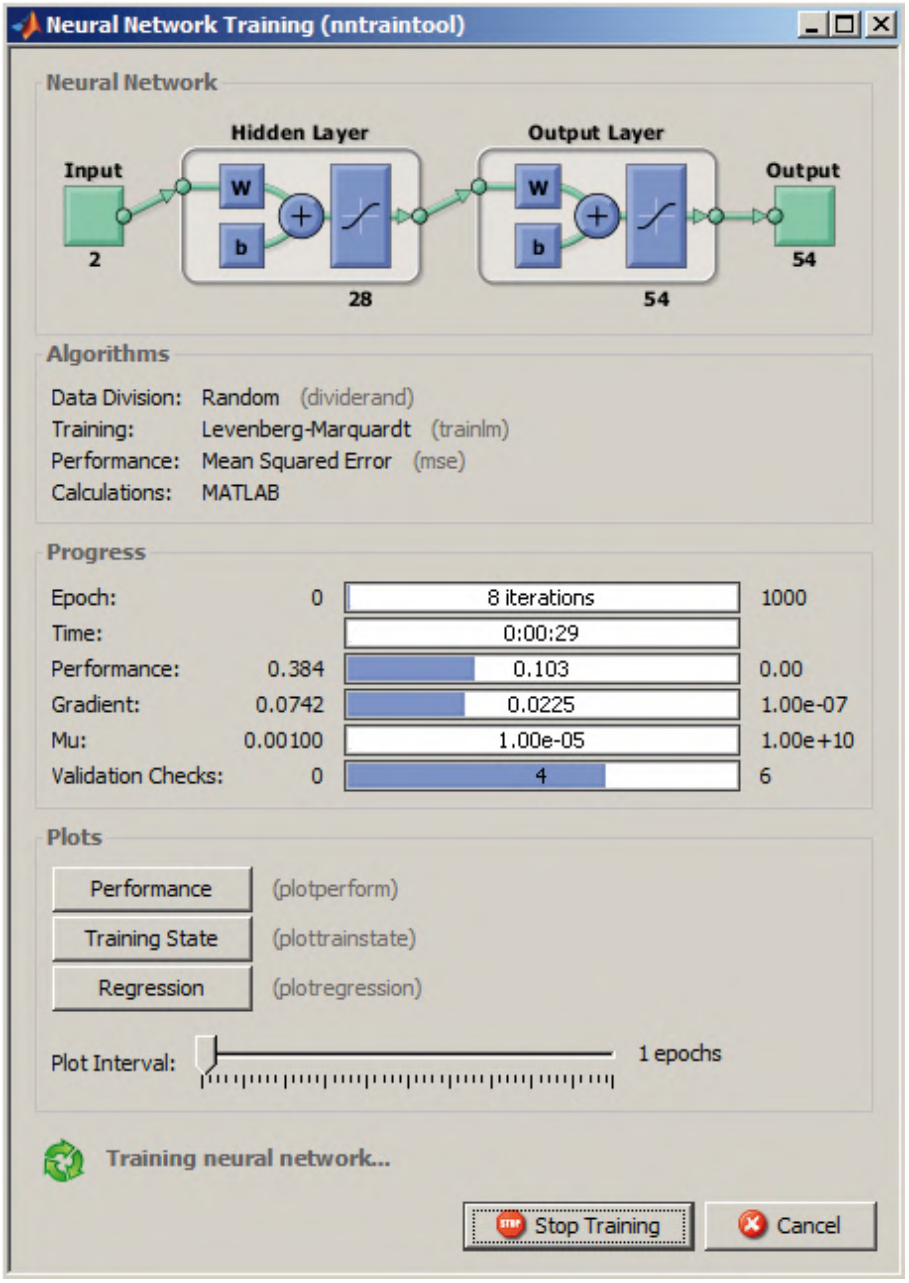


Figure 6: Neural network learning.

After the training was completed, two types of data appeared in the Neural Network / Data Manager window: Output Data (O) and Error Data (E). Double-clicking on data O opens a window with data output. By clicking the Export button in the manager window, and then clicking Export again in the window that opens, you can transfer the data to the Matlab workspace, where it will be presented in the most presentable form. You can view the results in the O.mat and E.mat files.

You can calculate that the average network error is 0.0321, which indicates the efficiency of the system.

After learning the network, you can proceed to data forecasting. Returning to the Neural Network /

Table 2
Output signals (O).

Indicators of quality criteria	Student grades								
	1	2	3	4	5	6	7	...	54
1	3.1985	3.252	3.3058	3.3541	3.3933	3.4235	3.4475	...	3.9704
2	3.4521	3.3478	3.2644	3.2035	3.1633	3.1404	3.1319	...	3.9997
3	3.1516	3.1812	3.219	3.2627	3.3062	3.3417	3.3638	...	3.9992
...	...	...	...	...	...	...	...	...	...
54	4	3.4192	3.3522	3.3128	3.291	3.2798	3.2756	...	3.9716

Data Manager window, you need to create additional input by clicking the New button. Going to the Data tab, the name of the data changes, for example, to P1, and the values are set as follows: values 1-54 still indicate the numbers of indicators of quality criteria of educational programs and educational activities, and 56-109 assessments of students and graduates quality, and the last column – projected expert assessments.

Next, you need to return to the Network window. In the Simulate tab of the input values house, the P1 array is selected, and the Outputs output value is renamed to forecast (figure 7).

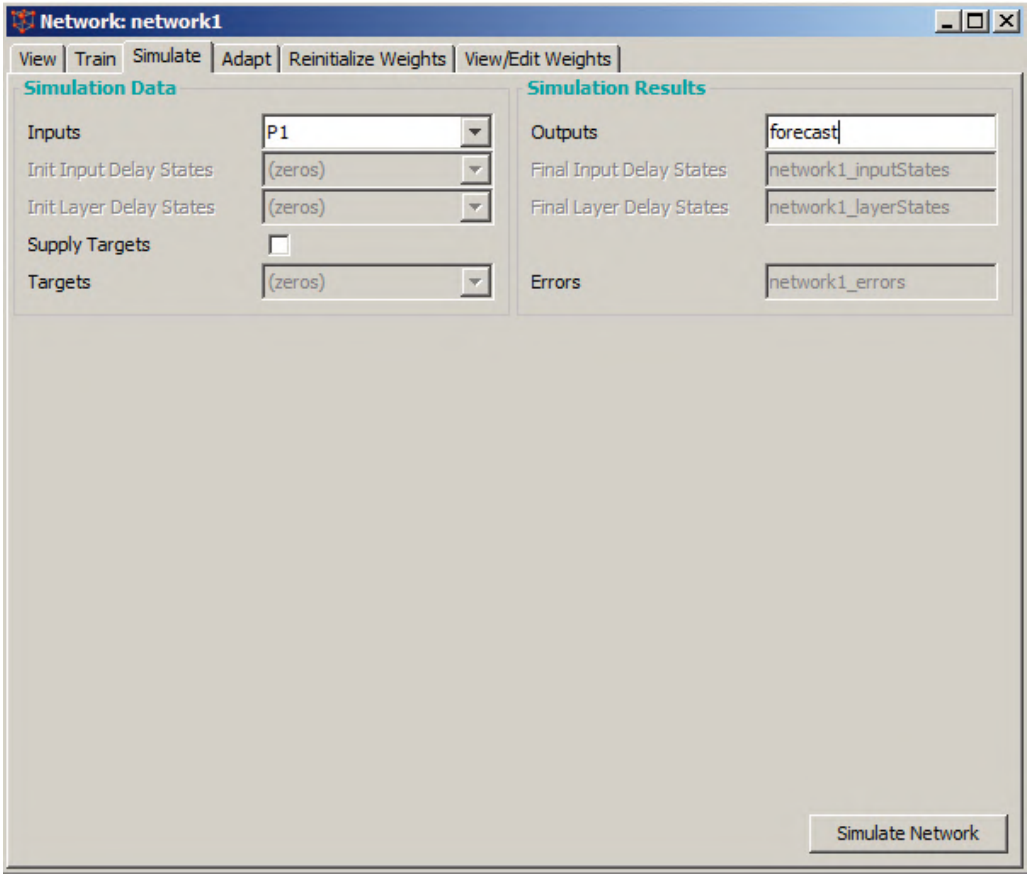


Figure 7: Simulate.

After clicking the Simulate Network button, you can return to the Neural Network / Data Manager window and, by clicking the Export button, copy the source forecast array to the Matlab workspace. After receiving the table in the workspace, pay attention to the last column, which is responsible for forecasting (figure 8).

The data obtained in the study can be viewed in the forecast.mat file.

Comparing the data issued by the system and the real data, we can see that the neural network does make predictions that are quite close to reality. Compared with expert estimates, the average absolute

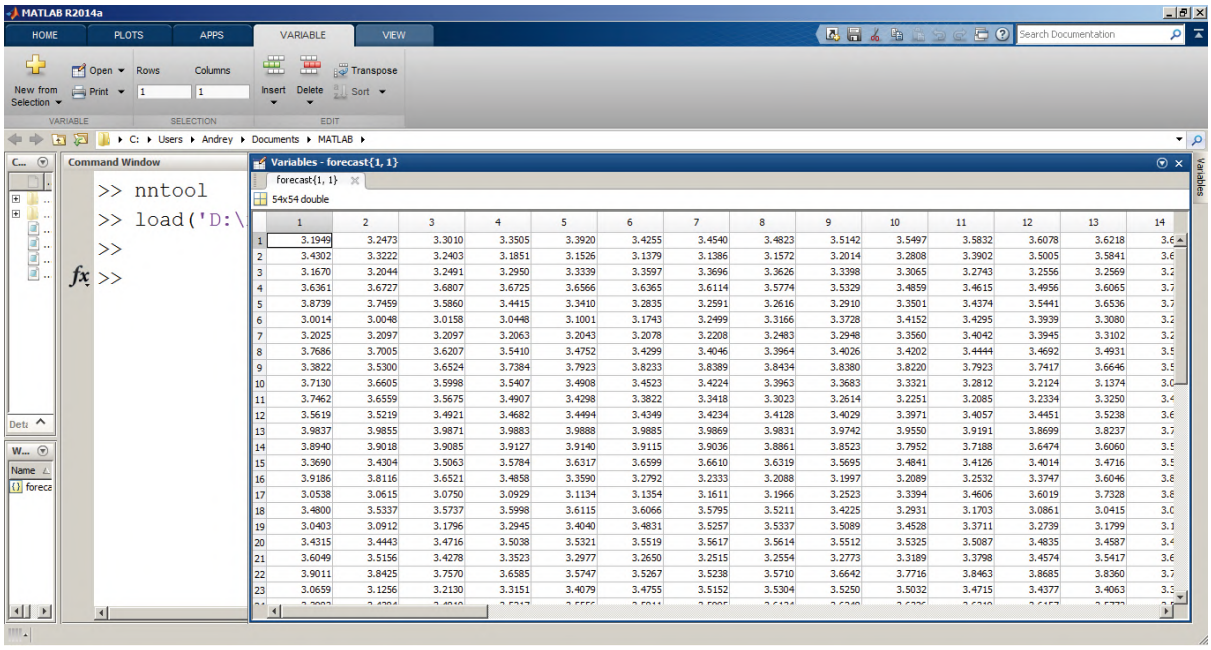


Figure 8: Getting a table with forecasting in the work area.

Table 3
Errors (E).

Indicators of quality criteria	Student grades								
	1	2	3	4	5	6	7	...	54
1	-0.199	0.748	-0.306	-0.354	0.607	-0.424	0.552	…	0.0000237
2	0.548	-0.348	-0.264	-0.203	0.837	-0.140	-0.132	…	0.029607
3	-0.152	-0.181	0.781	-0.263	0.694	0.658	-0.364	…	0.00027
…	…	…	…	…	…	…	…	…	…
54	0.58076	-0.3522	-0.3128	-0.2909	0.7202	-0.2755	-0.2769	…	0.028442

Table 4
Neural network forecast and expert evaluation.

Indicators of quality criteria	Forecast	Estimates
1	3.999977	4
2	3.974844	4
3	3.999750	4
4	3.999379	3
5	3.956661	4
6	3.991731	4
7	3.985698	4
…	…	…
54	3.970182	4

error is 0.0321, the relative error is 7.08%.

In the second part of the experiment, forecasting was carried out using a different type of neural network – a neuro-fuzzy network, or ANFIS-model.

Expert estimates are used as validation data. Create data files: training.dat, testing.dat, checking.dat. It should be noted that attempts to consider large data volumes lead to a reduction in the number of observations in the training sample and its simultaneous unjustified growth, which can negatively affect the network's ability to learn. So, first you need to turn the available information into a form

that is understandable and meaningful for the neuro-fuzzy network. Consider the average value of the assessment of each of the 10 criteria for assessing the quality of the educational program. For training, we use the average scores of all students for each of the 10 criteria. For testing, the marks of students numbered from 12 to 30 are used, for verification – the marks that were put by 31 students.

We preliminarily transpose the data, so the numbers of students will be in the rows, and the grades according to the quality criteria will be in the columns. The data in the files contains 10 columns – 9 grades (incoming) and 1 grade (source). The first file contains 54 lines and 10 columns. The second has 18 rows and 10 columns. The third has one row and 10 columns.

Training.dat file (first three lines):

3.5000 3.3333 3.5000 3.4000 3.5000 3.3333 3.3333 3.5714 3.3333 3.1667
4.0000 3.4444 3.2500 3.8000 3.7500 3.5000 3.6667 3.4286 3.6667 4.0000
3.2500 3.6667 3.2500 3.4000 3.5000 3.6667 3.0000 3.5714 4.0000 3.8333

Testing.dat file (first four lines):

3.2500 3.4444 3.7500 3.6000 3.2500 3.8333 3.5000 3.4286 3.6667 3.5000
3.7500 3.6667 4.0000 3.2000 3.5000 3.3333 3.1667 3.8571 3.6667 3.6667
4.0000 3.5556 3.5000 3.6000 3.5000 3.8333 3.5000 3.2857 3.3333 3.8333
3.5000 3.5556 3.2500 3.4000 3.5000 3.6667 3.6667 3.5714 4.0000 3.5000

Checking.dat file:

3.5000 3.3333 3.2500 3.4000 4.0000 3.3333 3.8333 3.2857 3.0000 3.8333

Anfis Editor is used to building MATLAB fuzzy neural networks. Run the editor with the anfisedit command. In the Load data menu, select Training, and From disk, click the load data button. In the window that opens, select the previously created training.dat file. In the Load data menu, select Testing and From disk, click the load data button. In the window that opens, select the previously created testing.dat. In the Load data menu, select Checking and From disk, and click the load data button. In the window that opens, select the previously created checking.dat. The visualization area contains two types of information: when training the system, the learning curve in the form of a graph of the dependence of the learning error on the iteration ordinal number; when loading data and testing the system – experimental data and simulation results.

Experimental data and simulation results are displayed as a set of points in two-dimensional space. In this case, the serial number of the data line in the sample (training, test, or control) is plotted along the abscissa axis, and the value of the initial variable of this sample line is plotted along the ordinate axis. The following markers are used: blue dot (.) – test set; blue circle (o) – training sample; blue plus (+) – control sample; a red asterisk (*) – simulation results.

Then, having set the Generate FIS menu switch to the Grid partition position, you should press the Generate FIS button. In this case, the model has 10 input variables, each of which corresponds to 9 terms of the gaussmf type. The original variable is determined by a linear function. Let's generate a Sugeno-type fuzzy inference system by pressing the Generate FIS button. In the window that opens, set 3 membership functions of the gaussmf type for each input variable. The choice of the property function here is because we assume a normal distribution for a random variable, defined by a Gaussian function according to probability theory. For the output variable, we set the membership function const.

To train the hybrid network, we will choose the backdrop method (error backpropagation) with an error level of 0 and a number of cycles of 10. Let's start training the hybrid network (figure 10).

As can be seen from figure 10, according to the training results, the average error is approximately 0.007.

We test the fuzzy inference system first on the training set.

Now let's test the resulting fuzzy inference system on the known values of expert estimates. Now we download this sample in testing mode in the Anfis editor. The results are shown in Figure 12. The mean score of the experts is 3.99; network prediction of the neural fuzzy network is 3.51. The relative forecast error is 12.57%.

Comparing the prediction errors of the neuro-fuzzy network (12.57%) and the L-layer feed-forward

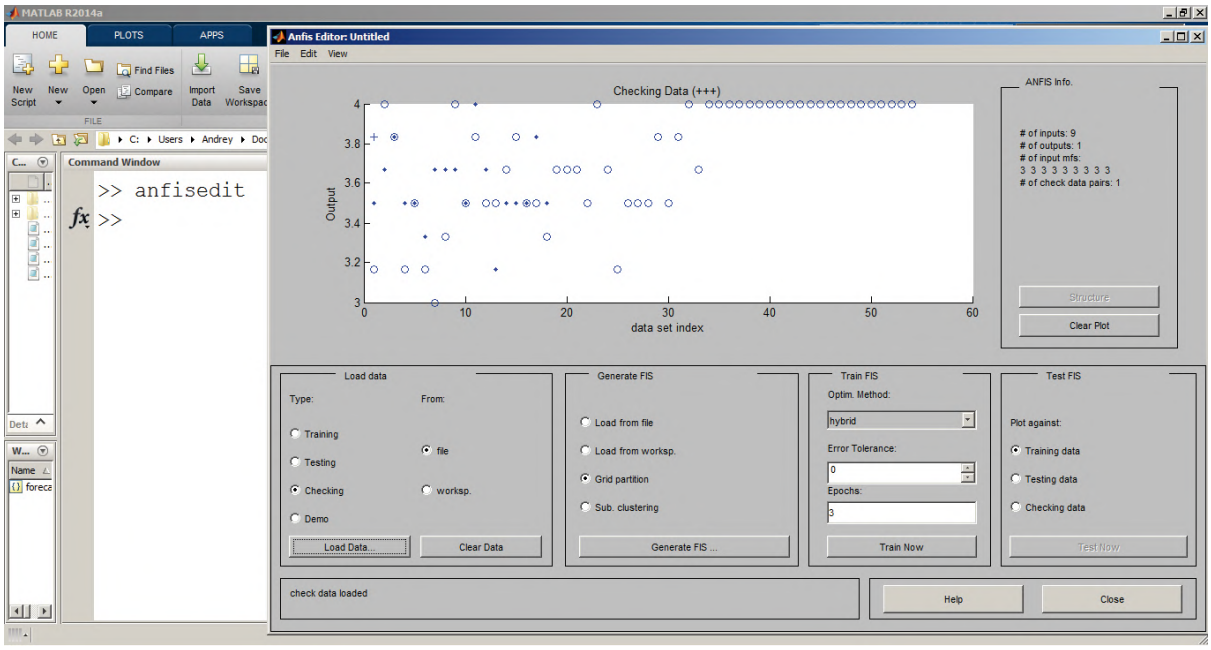


Figure 9: Data for network training and validation.

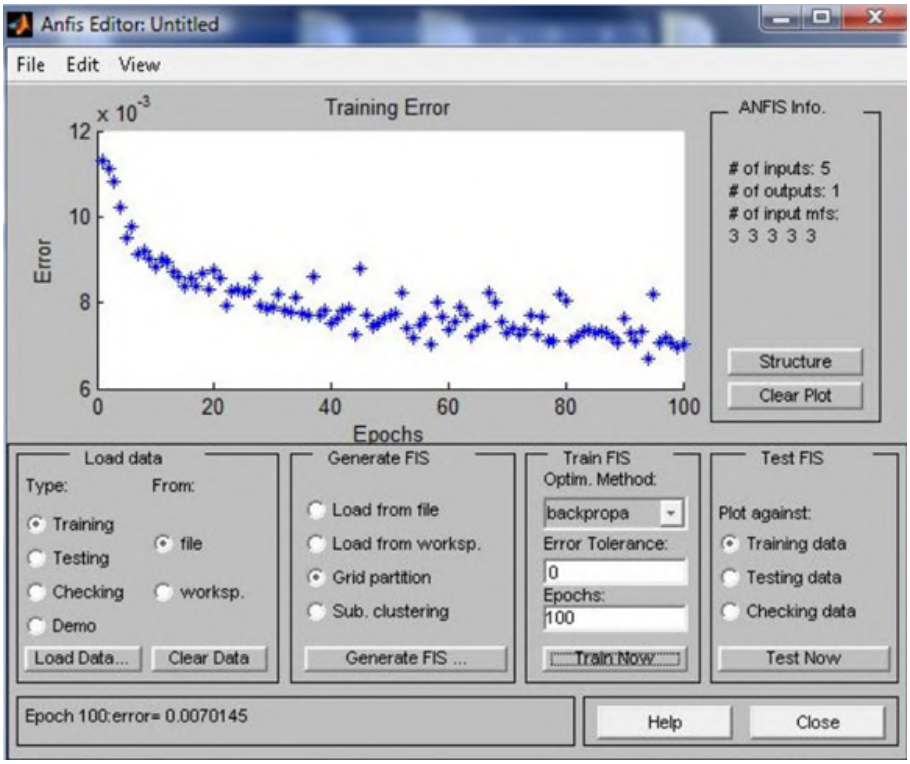


Figure 10: Network training error.

neural network (7.08%), we can see that the latter makes a more accurate prediction. It should be noted that the ANFIS model requires significantly more computing resources from the computer, which forced us to reduce the number of input variables to 10, which corresponded to the number of program evaluation criteria, and use the average values of quality indicators for each of the criteria. Of course, the problem requires further study of large data volumes of other accreditation examinations, but in general, this approach has demonstrated very good predictive capabilities.

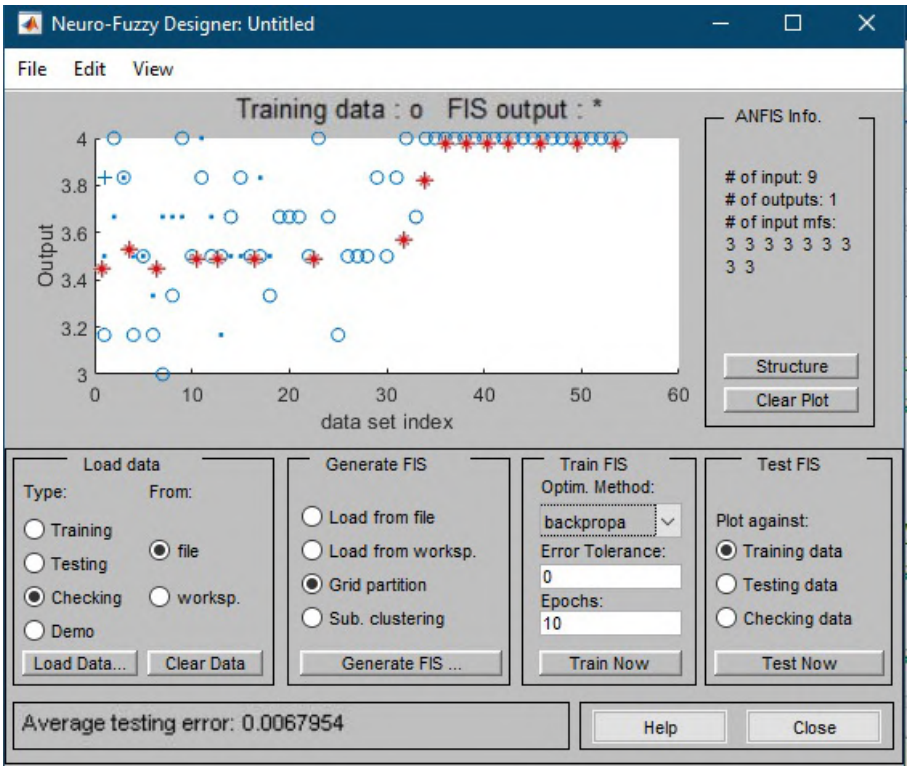


Figure 11: Network training results.

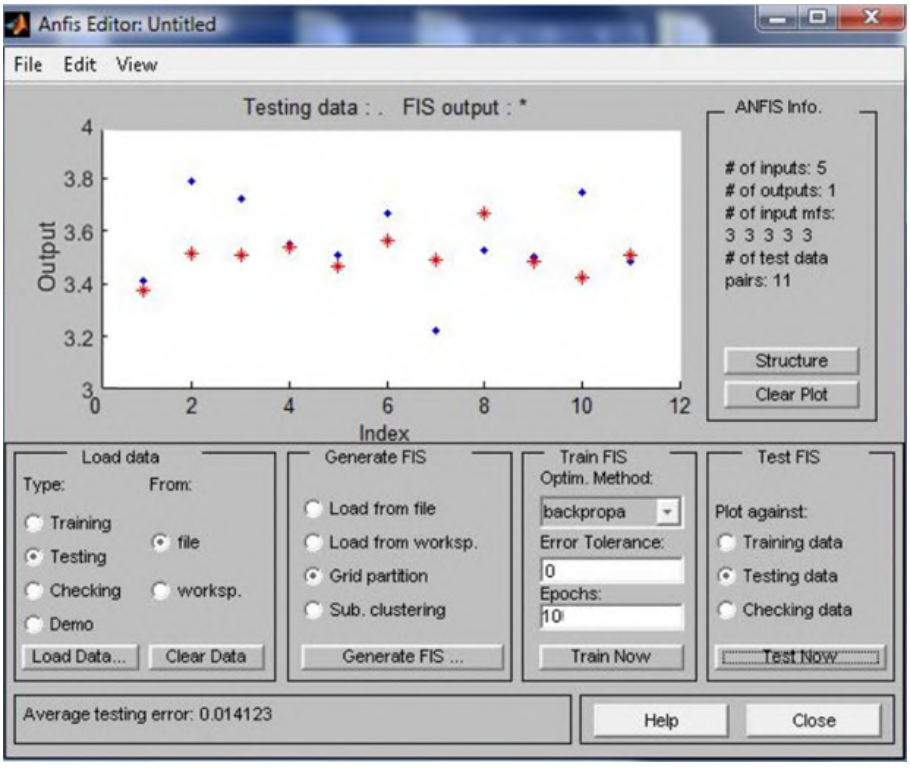


Figure 12: The results of network testing on known values of expert estimates.

Table 4 also shows that the quality of the program and educational activities is at a fairly high level, which reflects the average score of the peer review.

3. Discussion

The study aimed to demonstrate that the challenge of predicting the assessment of educational programme quality and institutional performance can be adequately addressed through an artificial neural network, obtaining a comprehensive evaluation based on a neuro-fuzzy approach. The mathematical model involves the use of neural networks and is based on the technology of analytical processing of statistical data. Standard methods of mathematical statistics are used to analyse the estimates received from respondents.

The proposals for using students as experts in evaluating educational programmes and institutional activities are debatable; it would be more appropriate to involve teachers from other educational institutions. However, in the process of preparing for self-assessment, this approach can be considered quite suitable.

The results of the neural network should be considered not as final, but as a test. As noted, for more detailed conclusions, it is necessary to train the network on a larger amount of experimental data.

The network structure has room for further improvement and customisation in future studies.

The assumption that a sample of students and graduates can prepare a dataset for setting up and teaching an artificial neural network to evaluate the quality of educational programmes and activities is confirmed by ordering the quality assessments of students and graduates in ascending order of their grade point average. In practice, this allows predicting the results and identifying existing shortcomings to eliminate them before the accreditation examination. However, the difficulty of this method lies in choosing the architecture of the neural network and preparing a training sample to configure it. In particular, future plans include increasing the volume of the input vector of the artificial neural network, with the form based on estimates of teachers, stakeholders, and experts.

4. Conclusions

As a result of developing a mathematical model for the comprehensive evaluation of educational programme quality and institutional performance based on neuro-fuzzy approaches, we have managed to achieve two key outcomes. Firstly, we have devised a mechanism for obtaining a quantitative assessment of educational programmes and activities that will enable higher education institutions to detect shortcomings and potential problems, and address them prior to accreditation examinations. Secondly, we have demonstrated that a sample of students and graduates can be used to prepare a training dataset for configuring and training an artificial neural network capable of adequately performing a comprehensive assessment of educational programmes and institutional activities. This can be accomplished by arranging the assessments of programme quality and educational activities provided by students and graduates in ascending order based on their grade point average. It is emphasised that these methods are effective provided they adhere to the principles of student-centredness and academic freedom.

By preparing a training sample for setting up and teaching an artificial neural network based on a sample of students and graduates, we were able to evaluate the quality of educational programmes and activities. A comparison of the results produced by an artificial neural network of direct propagation with one output and several inputs with real data shows that the neural network generates predictions close to reality. Compared with expert estimates, the average absolute error was 0.0321, and the relative error was 7.08%.

The results of this study can be applied in the practice of higher education institutions to predict outcomes, identify existing shortcomings, and eliminate them before accreditation examinations.

We see prospects for further research in the application of software products based on neural network theory to automate the processes of organisation, control, and analysis of the educational process, as well as the introduction of neural network software for the direct training of students in certain disciplines.

Declaration on Generative AI: The authors have not employed any Generative AI tools.

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Digital modeling of the ecophilic tendencies of university students' consciousness

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Abstract

The article presents a digital modeling of ecophilic tendencies of university students' consciousness based on the integrative application of digital, mathematical, anthropological, psychological methods and approaches. In order to determine the optimal number of clusters, we used the Hubert index and its graphical representation, hierarchical clustering with Ward's minimum variance method (Ward D and Ward D2) and its visual representation, distance matrix and visualization based on it. We clustered the objects using two clustering methods – K-Means and Canopy. Based on the study of ecophilic tendencies of consciousness using cluster modeling with the help of K-Means and Canopy methods, the 3rd and 4th clusters were formed. The 4 cluster models are more representative clustering models. In these models, the "ecophilic" clusters (25-28%) with medium and high levels of ecophilic tendencies of consciousness are defined as system-organizing, the "dominant" clusters (42-46%) with a slight development of ecophilic tendencies of consciousness; the "transitional" clusters (5-7%), which indicates the presence of "ecological potential" in the clusters with the lowest level of ecophilic tendencies of consciousness. This structure of clusters also reflects the presence of humanistic and democratic traditions in the system of which ecologization is realized in an intellectualized, aestheticized way, which corresponds to the ideology of sustainable development goals aimed at unlocking human potential. Accordingly, the results of the study of ecophilic tendencies in the consciousness of university students underlie the conceptualization of two directions of ecologization that can be simultaneously represented as existentially harmonizing and aesthetically harmonizing. The above directions are used to develop ecophilic tendencies of university students' consciousness, in particular, future mathematics teachers, students of information technology and to improve the health-saving competence of physical education teachers, in the system of which the ecological aspect is a significant factor for health preservation.

Keywords

ecophilic consciousness, digital modeling, cluster analysis, K-Means, Canopy, hierarchical clustering, Ward's method, sustainable development, ecological potential, university students, psychological modeling, mathematical modeling, anthropological approach, health-saving competence, environmental education, ecologization, humanistic traditions, aesthetic harmonization, existential harmonization, information technology education, physical education teachers

1. Introduction

Updating the anthropo-ecological visions of A. Peccei [1] and ecologically-valuably and ecologically-ethically understanding the significance of "Literacy for the Future" [2], we consider the development of the "New Man" – Homo Ecologicus, in which harmonious relations with the Earth are a master direction in the implementation of the strategic concept of Sustainable Development. Accordingly, we comprehend the leading importance for the future of the ecologization of education and pedagogical

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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

CEUR-WS.org/Vol-3918/paper056.pdf

science and practice, which are crucial in the formation of Homo Ecologicus. Ecologization is primarily aimed at developing ecophilic tendencies of students' consciousness, which are considered as ethical, value-semantic and emotional-value foundations of Homo Ecologicus. Thus, higher education with the existing cross-cutting ecologization is a crucial condition for the implementation of Sustainable Development.

In relation to the above educational and anthropo-ecological intentions, the professional activity of a teacher should be directed to the ecologization of the professional, cultural, intellectual, and health-preserving dimensions of human existence, which, accordingly, in our pedagogical system is considered in relation to the preservation of the Earth and harmonious interaction with it. The primary and main anthropological factor in the implementation of such a cross-cutting policy of ecologization is the teacher. For example, a teacher or lecturer, due to the peculiarities of his or her professional activity, has the opportunity to promote the disclosure of not only intellectual potential in students, but also the existential dimension of consciousness. This determines the possibilities and pedagogical ways to existential comprehension of the problems of interaction in the "Man-Earth" system. This is realized by actualizing the existentials of temporality, care, spatiality, heart, health, and corporeality in the educational process. In accordance with the ideology of sustainable development, in the process of ecologization, teachers need to reveal existential care in students, including care for the Earth, as well as develop kindness, tolerance, responsibility, anticipation (foresight, forecasting) aimed at preserving the planet. These qualities should not only be "purely anthropological", they should be initially formed as containing an ecological "dimension" and orientation. Thus, ecologization is relevant, as it promotes the development of "eco-anthropological intentionality" (orientation) of a person in the educational process. An important aspect of the development of "eco-anthropological intentionality" is the integrative realization of ecologization, aestheticization, ethicization, existentialization and psychologization of the educational process, which are aimed at forming a holistic, valuable and positive image of the Earth. A relevant aspect of these ecophilic transformations of consciousness is the development of focus not only on oneself and the Earth but also on the "Earth in the future" (futures literacy) [1].

Let's consider current research, including ecophilic-oriented research, which reveals the anthropological, ecological, and digital aspects of environmental awareness and modeling of relevant phenomena, processes, and systems.

Puk [3] reveals the risks of using digital technologies through their active implementation in primary and secondary schools. The researcher points out that digital technologies to a certain extent form a "two-dimensional world" and a non-plastic "new" reality that can distance children from healthy ecophilic interaction with nature.

Saboya de Aragão and Alfinito [4] study the influence of human values on the conscious environmental behavior of consumers in a developing country. The researchers point out that there is a lack of understanding of the relationship between human values and consumer ecological behavior, which should be taken into account when developing policies.

Pu et al. [5] analyzing the impact of COVID-19 on global social psychology, environmental sustainability and development, the researchers identify the presence of actualization of creativity, innovation, altruism, and compassion. The qualities identified by researchers are significant components of not only effective and humane social interaction, but are also considered by us as important aspects of ecophilic personality orientation.

Zhen, Yue and Yulong [6] studied the formation of ecological physical education of college on the basis of actualization of multidisciplinary approach, including the application of innovations, pedagogy, ecology, psychology and principles of ecology, integrity, dynamism, systematicity. According to the author, this ecologization of physical education contributes to the development of personality, health, and the disclosure of creative abilities.

Volkova, Proskurova and Yevsieieva [7] studied the attitudes of Ukrainian citizens towards environmental issues in the context of the theory of generations X, Y, Z. It was determined that citizens of three generations (X, Y, Z) share common ecological values, although Generation Z does not care about the environment.

Zhang and Liu [8] study the smart home (ESHS). The authors use the theory of the technology

acceptance model to update the knowledge of ecological awareness.

Mulrow, Gali and Grubert [9], studying digital technologies as cyber-physical systems (CPS), point to their favorable impact on ecological results. The authors argue for the need to take CPS into account in ecological assessment. Thus, it is possible to articulate the idea of a certain integration of the digital and natural environment, which determines the opening of new opportunities for both the ecologization of consciousness and the development of digital technologies.

Galati et al. conducted a study to investigate the environmental motives for students of the University of Palermo to choose to buy water in bio-bottles [10]. The researchers applied fuzzy clustering methods, since they believe that the data obtained are not mutually exclusive, and the objects of clustering can belong to several clusters.

Lian, Qian and Bao [11] investigates ecological behavior based on structural equation modeling (SEM). Based on their model, the researchers point to a positive relationship between environmental awareness, risk perception, cognitive capacity, law-abidingness, and environmental behavior.

Arya and Kumar [12] use Value Behavior Norm Theory to study the ecological behavior of university students. They show that the presence of altruistic and egoistic values and responsibility significantly predict pro-ecological behavior. At the same time, the presence of biosphere values, awareness of consequences and personal norms are not significant for pro-ecological behavior.

Park, Kwon and Kim [13] studied the impact of green information transmitted through online platforms and the moderating role of ecological awareness on customers' ecological perceptions. The researchers note that green information contributes to customer satisfaction.

At present, four relevant interrelated and interdependent strategies can be identified in education – actualization of human potential, innovation, humanization and ecologization [14], which are implemented on the basis of student-centeredness, partnership pedagogy, values-based education, competence-based and activity-based approaches. One of the system-organizing and transformative strategies of education is the formation of "environmental competence" [15], which is carried out on the basis of the development of ecophilic tendencies of consciousness and the actualization of ecophilic cultural values and meanings and value-sense contexts.

Human consciousness, which is actively influenced by education, is the primary, determining and system-organizing factor in the realization of sustainable development goals and the development of future ecocentric transformations of relations between humans and the planet Earth. Education is primary and decisive in the formation of both ecologically oriented cultural values, ethical intentions and understandings, value and meaning contexts, and a new human being – Homo Ekologicus. In addition, in the processes of ecologization, which are legitimized by program documents and legislative acts, the educational sphere is also a defining and system-organizing one.

An important aspect of the educational implementation of greening and its disclosure as a cultural and educational trend is the use of digital technologies [16]. Despite the wide representation of ecologization in the scientific pedagogical literature, the problem of digital modeling of ecophilic tendencies of consciousness is not sufficiently addressed. Given the importance of the development of ecophilic tendencies of consciousness for the realization of sustainable development goals, we define this problem as relevant.

The purpose of the study is to digitally model ecophilic tendencies in the consciousness of university students.

2. Selection of methods and diagnostics

The methodology of modeling ecophilic tendencies of university students' consciousness was developed through the integrative application of mathematical and informatics approaches, as well as using methods of ecology, anthropology and humanities. Accordingly, this methodological system is represented by: ecological, competence, health, systemic, ecological and anthropological, ecological and psychological [17], ecological and pedagogical [14, 18], reflective, axiological, problematic, ecological and ethical, psychological, existential, transdisciplinary approaches and methods.

In the system of this study, the methodological potential of the following concepts is actualized: sustainable development [19, 20], sustainable development goals [21], New Enlightenment, Earth Charter and the Visual Turn paradigm [22] and the ecological paradigm.

The study used mathematical and informatics methods and approaches [23, 24]: system analysis, cluster analysis [25, 26, 27, 28, 29], methods of mathematical statistics, digital modeling, digital data visualization, etc. Let us consider some of them.

To determine the optimal number of clusters in the dataset, we used the Hubert index and its graphical representation, hierarchical clustering with Ward's minimum variance method (Ward D and Ward D2) and its visual representation, distance matrix and visualization based on it.

According to the Hubert graphical method, the optimal number of clusters is determined. For a square proximity matrix P ($n \times n$) of the data set and a square matrix R ($n \times n$) of distances between representative points (rc_i, rc_j) of the corresponding clusters, which include elements x_i and x_j, the Hubert index (H) (1) is calculated using the following formula [27]:

$$H(P,R) = \frac{1}{N}\sum_{i=1}^{n-1}\sum_{j=i+1}^{n} P_{ij}R_{ij}, \tag{1}$$

where:

n is the dimension of the matrix;

$N = \frac{n(n-1)}{2}$;

P is an $n \times n$ the proximity matrix;

R is an $n \times n$ the distance matrix between the representative points;

i, j are indices of rows and columns of the matrix, $i = 1, \ldots, n$ and $j = 1, \ldots, n$.

It should be noted that if the number of clusters is equal to 1 or n, the Hubert index is not defined.

In the Dindex Value plot of the Hubert index we need to determine a significant deviation, which corresponds to a significant increase in the value of the index. In the Second differences Dindex Value plot of Hubert index, you need to determine the significant peak. Significant deviation and significant peak determine the optimal number of clusters.

The Hubert graphical method was implemented using the R [30] language in the Posit Cloud environment [31]. The NbClust package was used. The Euclidean distance measure (d) (2) was used as an argument to calculate the difference matrix [27]:

$$d(x,y) = \left(\sum_{j=1}^{n}(x_j - y_j)^2\right)^{\frac{1}{2}}, \tag{2}$$

where:

n is the dimension of the vector;

j is an index, $j = 1, \ldots, n$;

x and y are standardized n-dimensional vectors, $j = 1, \ldots, n$.

Hierarchical clustering with Ward's minimum variance method (Ward D and Ward D2) was also used to diagnose the optimal number of clusters. For this purpose, a distance matrix was constructed using the Euclidean distance measure (d) (**??** [26, 28]. Hierarchical data agglomeration based on the distance matrix was implemented using the Ward D and Ward D2 methods [32]. Ward's minimum variance method is a hierarchical clustering algorithm aimed at minimizing the increase. In our case, it is appropriate to use it because it is assumed that the clusters will have different sizes and densities. The result of applying Ward's method is a dendrogram that visualizes the hierarchical structure of clusters [32]. Ward's linkage is calculated as the within-cluster sum of squares (within-cluster inertia), the distance dc ((3) and (4)) between clusters X and Y after their merging, and characterizes the increase in the error sum of squares (ESS) when two clusters are merged at each step [32, 33, 34]:

$$dc(X,Y) = ESS(X,Y) - [ESS(X) + ESS(Y)], \tag{3}$$

where ESS is calculated by the formula

$$ESS(A) = \sum_{i=1}^{N_A} \left| a_i \ - -\frac{1}{A_X} \sum_{j=1}^{N_A} a_j \right|^2 , \tag{4}$$

where:

N_A is the numbers of elements in the cluster A;

i, j are indices of the elements of the A clusters, $i = 1, \ldots, N_A$ and $j = 1, \ldots, N_A$;

a_i and a_j are the elements of the A clusters, $i = 1, \ldots, N_A$ and $j = 1, \ldots, N_A$.

The Ward D and Ward D2 methods used by us differ in that the Ward D method in the minimize the increase process determines the sum of squares of deviations from the mean of the merged cluster, and the Ward D2 method determines the sum of squares of deviations from the centroid of the merged cluster (differences between clusters are more clearly distinguished, which makes them easier to identify) [32].

The graphical method based on the distance matrix was implemented using the R [30] language in the Posit Cloud [31]. The $dist()$ function was used, with $method = "euclidean"$ (2) as its argument.

In order to determine the clusters of objects, we used two clustering methods, K-Means and Canopy, described in more detail in the study of Klochko et al. [28].

The *K-Means* algorithm can be generally described as follows [28]:

1. The number of clusters (k) is determined. Select the required number of points to create the initial cluster centers. As the initial centers (centroids) of the clusters, k points are randomly selected from a given set of points.
2. Calculate the Euclidean distance of each point to the cluster centroid.
3. Point is assigned a cluster number that corresponds to the number of the nearest centroid k, the Euclidean distance to which is minimal.
4. The coordinates of the centroids of all clusters are listed.
5. Stages 2, 3, 4 are repeated until the change of centroids stops or the specified number of iterations is reached.

The Canopy algorithm is one of the simplest, most accurate, fastest methods. The Canopy algorithm is often used for pre-clustering data. The algorithm uses two distance thresholds: the loose distance ($D1$) and tight distance ($D2$), $D1 > D2$.

A general description of the *Canopy* algorithm is as follows [26, 35]:

1. Clustering objects are represented as points in a multidimensional feature space.
2. One point is randomly deleted to create a canopy (cluster) containing this point.
3. Each point remaining in the set is assigned to a new canopy (cluster) if its distance to the first point of the canopy is less than the loose distance $D1$. If, in addition, the distance of the point is less than the tight distance $D2$, it is removed from the initial set of points.
4. Repeat steps 2 and 3 until the initial set of points is empty.

Before using the above methods for determining the optimal number of clusters and data clustering methods, the data is normalized. In our case, the answers to the questions were assigned values of $0, 1, 2, 3$, and there were no peak values, so we did not perform data normalization. Also, before applying these methods, we did not clean the data, since the electronic questionnaire options required answering the question in the equivalent range of $0, 1, 2, 3$.

The authors used their own methodological developments, namely, the "Fedorets' Questionnaire for Determining Ecophilic Tendencies of Consciousness".

"Fedorets' Questionnaire for Determining Ecophilic Tendencies of Consciousness":

1. I find beauty in various landscapes of natural origin.
2. I see beauty and perfection in natural things – stones, water, mud, animals, insects, flowers, roots, weeds.

3. Swamps, deserts, and impenetrable forest thickets do not disgust or dislike me; they are beautiful in their own way.
4. I feel very sorry for wild animals in zoos and laboratory animals.
5. It is painful for me to see how the Earth's natural landscapes are being destroyed.
6. I am concerned about the future of the Earth, from which its authentic natural landscapes may disappear.
7. I feel very sorry for animals and plants that may disappear from the Earth forever.
8. I feel sorry when old trees are cut down that may still be growing.
9. It is painful for me to watch the earth being covered in concrete and asphalt without any urgent need.
10. I feel sorry for the planet Earth as a living being that is being destroyed and "suffering" from the total impact of man.

The variants of answers to the questionnaire: 1 – No; 2 – Yes; 3 – Yes+; 4 – Yes++.

Let us consider the ideas and meanings on the basis of which the Fedorets' Questionnaire for Determining Ecophilic Tendencies of Consciousness was developed.

The questionnaire is based on the idea of a holistic, panoramic, multidimensional and aesthetically oriented perception of the Earth in a visual format as a landscape, as a painting [22]. This aspect reflects the aesthetically oriented stereometric nature of human perception and actualizes the understanding of spatial perspective characteristic of European consciousness, which to some extent correlates with cosmism, anthropocosmism, and multidimensionality. The idea of the diversity of manifestations of earthly landscapes, presented aesthetically as landscapes, is important. This aspect is reflected in Question 1: "I find beauty in various landscapes of natural origin".

Question 2: "I see beauty and perfection in natural things – stones, water, mud, animals, insects, flowers, roots, weeds" contains the idea of perceiving reality as special unique phenomena, which, according to E. Husserl [36], are correlated with certain structures of consciousness. Phenomenology (German: Phänomenologie – "the doctrine of phenomena") "returns" us to the primary cognition of things (E. Husserl's famous idea "Back to the things themselves!"), to their primary, often unique and unified meanings. The earth, which "gives rise" to various phenomena, gives us the opportunity to comprehend them as beauty, as well as a panorama of earthly and vital meanings, which, in turn, helps us to reveal a sense of unity with the earthly, understood as alive, and forms respect for it and admiration for it. An important aspect is the phenomenon of biodiversity as a manifestation of life and the Earth.

Question 3, "Swamps, deserts, and impenetrable forest thickets do not disgust or dislike me; they are beautiful in their own way", contains the idea of an aesthetic and ethically oriented perception of the Earth and its landscapes as diverse and unique, as such, through which special elements, Forces, and spiritual entities manifest themselves. The power and meaning of the Earth's elements is not always revealed in a "pastoral" perfectly created landscape. Earthly elements can generate "elements" of chaos and tension. In addition, this question reveals ways to an ecophilic, value-based, and ethical understanding of the phenomenon of "wilderness" [37], through which the non-anthropogenic nature of the earthly is manifested.

Question 4: "I feel very sorry for wild animals in zoos and laboratory animals" refers to the manifestation of human nature through the ability to sympathize with the living and, above all, with animals that have a sufficiently developed psyche, feel pain and often understand the fact of their "slow" death or prolonged suffering in a laboratory or zoo. The idea of developing this issue, in addition to our own understanding of it, was formed by E. Frome in his concept of biophilia [38], the essence of which is the focus on the love of the living and the creation of new things.

Question 5: "It is painful for me to see how the Earth's natural landscapes are being destroyed" reflects the deep multidimensional connection between humans and the Earth. In the system of this interaction, humans and the Earth are presented as one. Therefore, the destruction of the landscape is felt and experienced as its own problem and its own tragedy. This question also diagnoses the presence or "limitations" of the anthropocosmic dimension of consciousness, within which a person consciously

or unconsciously feels part of the vast earthly cosmos. The system-organizing aspect of this question is the consideration of the significance and value of landscapes for humans as a "manifestation" of certain landscapes and, accordingly, a holistic, aesthetic, stereometric perception of the earth.

This Question 5, as well as Questions 1, 6, 9, and 10, are formed in the spirit of the Visual Turn [22] as a humanitarian direction aimed at actualizing and studying visuality. We use the ideas of this direction to actualize visuality in the individual and develop visual culture, which is presented as ecologically oriented.

Question 6: "I am concerned about the future of the Earth, from which its authentic natural landscapes may disappear" is a clarification of the previous Question 5. In addition to actualizing the existentials of care and spatiality, this question is aimed at manifesting human temporality and anticipation (the ability to foresee, which includes the actualization of the metacognitive level of consciousness). This, accordingly, reveals and actualizes the ability to think about the future of the Earth and determines the presence of ecophilic metacognitive strategies in the form of goal setting, reflection, planning and foresight.

Question 7 – "I feel very sorry for animals and plants that may disappear from the Earth forever" is essentially a clarification and expansion of the previous Questions 5 and 6. Although it has its own special vital (in the sense of life) and biophilic-oriented meaning. This question relates directly to the problem of life, which is embodied in the "kingdoms" of flora (plants) and fauna (animals). The existentials of topicality, love, care, and responsibility are actualized in this issue. It is responsibility that is to a certain extent personalized and largely related to living beings, which stand out as special from the "panorama" of inanimate objects and from the landscape and are considered as "special living worlds" essentially close to humans.

Question 8 – "I feel sorry when old trees are cut down that may still be growing" – reflects the attitude towards flora and towards the landscape and life in general, which is largely shaped by vegetation. This question reveals the problematic of the existing or absent experience of being in the natural environment and the ability to interpret it in an ecophilic way. An important spiritual and archetypal aspect is the ability to comprehend by actualizing this issue the concepts of the world tree (Latin: Arbor mundi) and the tree of life (Latin: Arbor Vite; English: Tree of Life; Hebrew: עֵץהַחַיִים: Etzheim, Tree of Paradise) as one of the main symbols of many world cultures. The tree of life and the world (cosmic) tree are seen as distinct spiritual, mythological, or archetypal (according to C. Jung) phenomena. Traditionally, it is believed that the symbolism of the tree is vital and it reflects the essence of life itself.

Question 9 – "It is painful for me to watch the earth being covered in concrete and asphalt without any urgent need" reveals the understanding of the Earth and its landscapes and landscapes and their reflection in the existential "depth" of a person, in their intrinsic value and givenness, as a manifestation of a living entity that has the ability to feel and suffer, and not just as a "dead" resource. Such an understanding can emerge as a result of life practices and experiences of communication with nature, provided that at least "elementary" positive intentions towards the "living world" (biophilia according to E. Frome) are revealed in the human soul [38]. This value attitude towards nature is mainly possible as a manifestation of the ecophilic nature of humans.

Question 10 – "I feel sorry for the planet Earth as a living being that is being destroyed and "suffering" from the total impact of man" is inherently generalizing, philosophical, anthropocosmic, and transforming ecological problems into a being, sensual, and heartfelt format. For an authentic (in the sense of one's own) comprehension of this issue, a certain life, sensual, intellectual, life-creating and spiritual experience and understanding is necessary. Undoubtedly, a positive solution to this issue is also possible as a result of the indoctrination of the ideology of ecologism into the public consciousness. In this issue, the idea of compassion is seen as a manifestation of the spiritual nature of man, his cordiality, mercy and kindness. This issue is aimed at harmonizing the relationship between man and the Earth.

Experimental base of the study: Berdyansk State Pedagogical University; Vinnytsia Academy of Continuing Education; Mykhailo Kotsiubynskyi Vinnytsia State Pedagogical University; Dragomanov Ukrainian State University; Vinnytsia Humanitarian and Pedagogical College; Vinnytsia National Technical University. The study, which was conducted in 2021-2022, involved 166 students, including teachers undergoing advanced training.

3. Results

The realization of the sustainable development goals [21] is possible, first of all, provided that a modern person acquires an ecophilic orientation of his or her consciousness. The ecologically oriented interpretation of human consciousness, which is considered as a determining anthropo-psychological factor in the preservation of the Earth and the realization of sustainable development goals, is revealed in this study on the basis of actualization of ecological-anthropological, ecological-psychological, ecological-pedagogical [14] and ecological-ethical approaches and visions. Accordingly, the idea of actualizing the ecological orientation of Homo sapiens' consciousness is defined as system-organizing and defining. This idea in this study is presented in the format of ecophilic tendencies of consciousness. Accordingly, ecophilic tendencies of consciousness are aimed at actualizing anthropological strategies for achieving the goals of sustainable development not only through technological progress, but primarily through changes in human behavior, which is based on the formation of environmentally oriented human qualities. This determines the need to model ecophilic tendencies of consciousness.

Having analyzed the ideas and developments of researchers who have studied various aspects (ecological, spiritual, philosophical, socio-political, educational, psychological, cultural and ethnic, anthropological) of ecological consciousness [14], ecophilia, biophilia [38], we can present the definition of the concept of "ecophilic tendencies of consciousness".

Ecophilic tendencies of consciousness are a system of intentions (orientations of consciousness), values, meanings, attitudes, which are a manifestation of the biophilic dimension of human nature, as well as and to a large extent, are conditioned by the socio-cultural sphere and represent a system of psychological patterns associated with the vital and existential spheres and the personal principle, existential and value-sense spheres and the personal principle, and accordingly determine a good, harmonious, tolerant, reasonable, constructive attitude towards the environment and the Earth, which is considered as a living being or entity endowed with special qualities and one of the highest values, and underlie ecophilic behavior.

In order to conduct the study based on the results of the questionnaire and given that the application of the methods specified in the section "Selective methods and diagnostics" involves processing data in a numerical format, the values of the test results were replaced accordingly: "No" to 0, "Yes" to 1, "Yes+" to 2, "Yes++" to 3 (table 1). Q1, Q2, ..., Q10 are denoted respectively as Question 1, Question 2, ..., Question 10.

Table 1
Correspondence table to present the test results in a numerical format.

Answer to the question	Numerical format of the answer to the question
No	0
Yes	1
Yes+	2
Yes++	3

As a result of testing students of higher education institutions using the Fedorets Questionnaire for Determining Ecophilic Tendencies of Consciousness, we obtained the data set shown in figure 1. The results of the testing are also presented below in the format of a bar chart (figure 2).

Let's analyze the results of the "Fedorets' Questionnaire for Determining Ecophilic Tendencies of Consciousness", presented in figure 2 according to each question of the test.

The answer "Yes" (marked as 1 in the diagram) is represented by the highest percentage of responses to all the questions in the questionnaire. It reflects the lowest intensity of a positive response – in almost all the questions studied, the percentage of "Yes" answers is approximately 50%, with a range of fluctuations of about ±10%. This indicates a positive understanding of the problem, which is inherent in half of the respondents. At the same time, the low intensity of the positive response combined with a significant number of people who have it (about half) indirectly indicates the instability of the existing

```
'data.frame':  166 obs. of  10 variables:
 $ Q1 : int  2 3 1 3 0 2 3 1 2 1 ...
 $ Q2 : int  1 3 1 2 0 2 3 1 1 1 ...
 $ Q3 : int  1 1 0 1 1 3 3 1 1 1 ...
 $ Q4 : int  2 2 2 1 3 2 1 1 3 0 ...
 $ Q5 : int  3 2 3 1 3 2 2 1 3 1 ...
 $ Q6 : int  1 1 1 1 0 2 1 1 3 1 ...
 $ Q7 : int  3 3 2 1 1 3 1 1 3 0 ...
 $ Q8 : int  3 1 2 1 0 3 0 1 2 0 ...
 $ Q9 : int  3 3 2 1 0 3 1 1 2 0 ...
 $ Q10: int  3 3 2 1 0 3 2 1 3 0 ...
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Figure 1: Dataset of test results.

ecophilic tendencies of consciousness. This is especially significant given the fact that the respondents are familiar with ecological issues in the course of their educational and professional activities.

In addition to the answers to questions Q8 "I feel sorry when old trees are cut down that may still be growing" and Q9 "It is painful for me to watch the earth being covered in concrete and asphalt without any urgent need", negative answers amount to 31.3% and 33.7%, respectively. These values make up about 1/3 of the answers to the question, are significant in size and characterize the presence of rather stable ecophobic tendencies, especially if we take into account that the respondents are quite familiar with ecological issues. Such a large number of negative answers can be explained as follows: these questions reflect specific phenomena that are significant simultaneously in aesthetic, economic and worldview aspects; there is a persistence of cultural and professional ecophobic stereotypes of a pragmatic and "simplified" aesthetic orientation that determine the specifics of the answers; there are absent or unstable ecophilic stereotypes that could be competitive with ecophobic ones. These questions are those in which environmental issues are revealed in specific phenomena presented as a practical problem to be solved.

The true attitude towards the Earth and nature is largely determined by these specific issues. It is one thing to "love" nature, the Earth "at a distance" or "in general" and another to solve specific problems and issues. Based on the significant importance of these two issues for the practice of nature conservation, we believe it is necessary to conduct research in this area, as well as to include these specific questions as relevant when considering environmental issues in universities, colleges and schools. Question Q8 "I feel sorry when old trees are cut down that may still be growing" can be interpreted in its expanded form as "Will the forest remain in a certain area as a result of economic activity?" Question Q9 "It is painful for me to watch the earth being covered in concrete and asphalt without any urgent need" can be interpreted more broadly as "Is every piece of land with unique natural landscapes being built up?".

In order to determine the groups of students according to the degree of manifestation of ecophilic intentions and values, we will apply cluster analysis.

Let's determine the optimal number of clusters in the data set that represents the results of testing using the "Fedorets' Questionnaire for Determining Ecophilic Tendencies of Consciousness" using the Hubert index, Ward's minimum variance method (Ward D and Ward D2), and distance matrix.

In the process of applying the Hubert index, the results are presented in table 2 and figure 3.

Table 2
Proposition of the best number of clusters among all indices by the Hubert method.

Number of clusters	Proposal of the best number of clusters
2	4
3	14
4	4
5	1

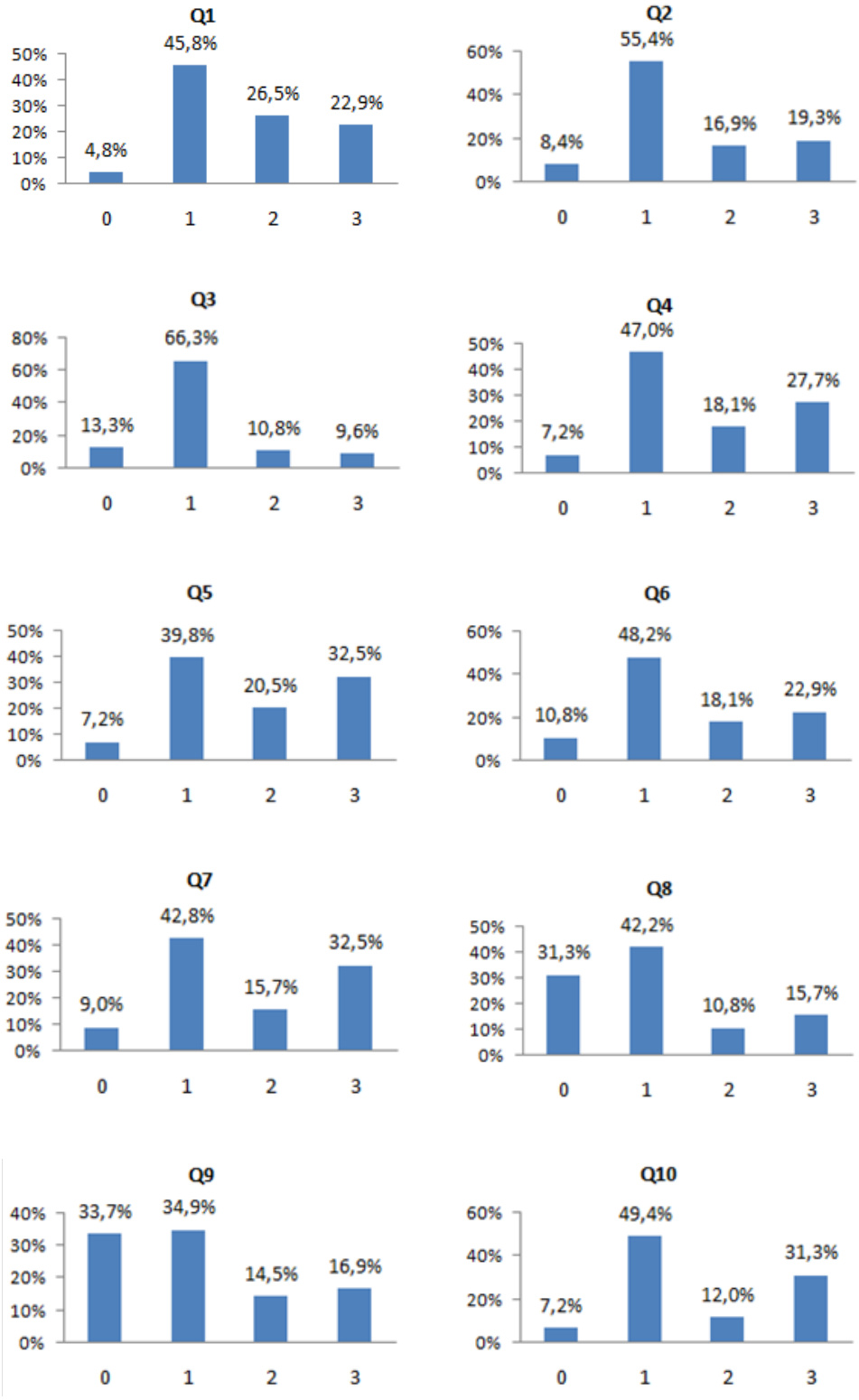


Figure 2: Dataset of test results.

According to table 2, according to the majority rule, the number of clusters 3 received the most proposals (14). There were also 4 proposals for the number of clusters 2 and 4.

According to figure 3 Dindex plot, a significant knee is observed at the number of clusters 3. According

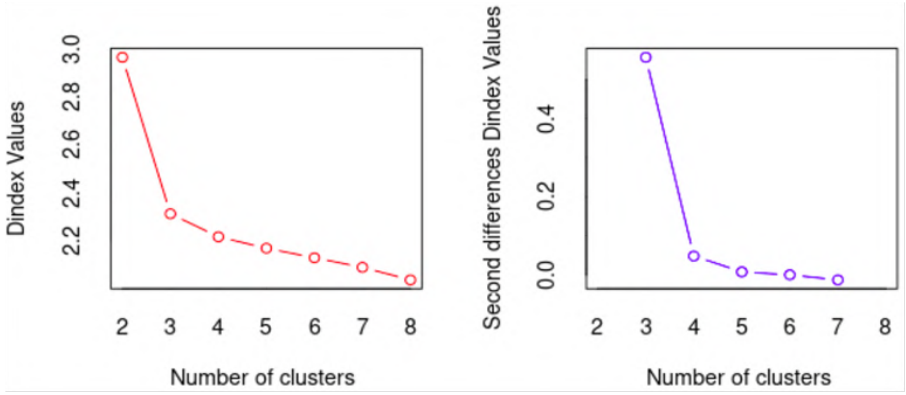
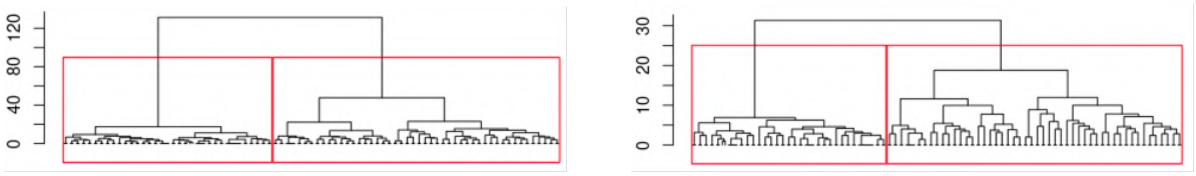
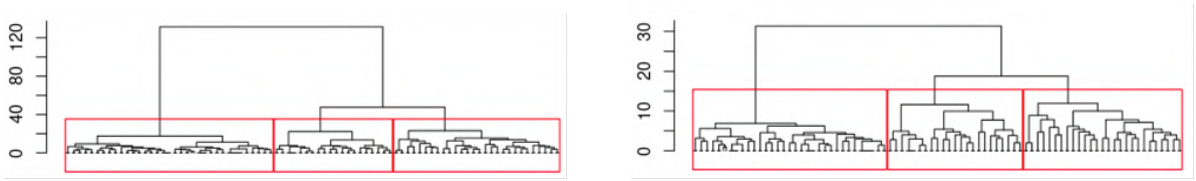


Figure 3: Graphical representation of the Hubert index application results Graphical representation of the Hubert index application results (Dindex plot and Dindex second differences).



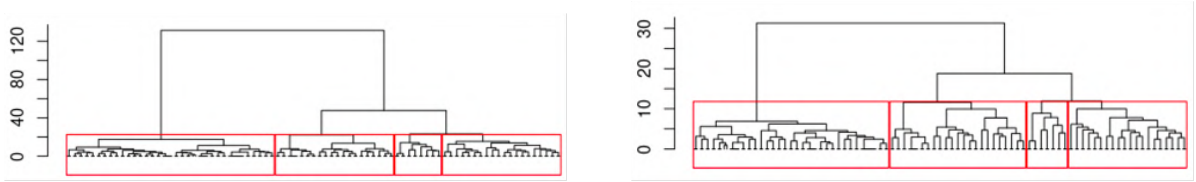
(a) *(b)*

Figure 4: Dendrogram of the hierarchical structure of clusters based on Ward's minimum variance method (Ward D (a) and Ward D2 (b)), 2 clusters are identified.



(a) *(b)*

Figure 5: Dendrogram of the hierarchical structure of clusters based on Ward's minimum variance method (Ward D (a) and Ward D2 (b)), 3 clusters are identified.



(a) *(b)*

Figure 6: Dendrogram of the hierarchical structure of clusters based on Ward's minimum variance method (Ward D (a) and Ward D2 (b)), 4 clusters are identified.

to figure 3 Dindex second differences plot the ignificant peak is also observed at the number of clusters 3.

As a result of using hierarchical clustering based on Ward's minimum variance method (Ward D and Ward D2) to diagnose the optimal number of clusters, the results are shown in figure 4, figure 5 and figure 6. The selected clusters in these figures are highlighted by red frames.

Thus, according to the results of hierarchical agglomerative clustering based on Ward's minimum variance method (Ward D and Ward D2), based on visual analysis and considerations of possible interpretation of the clusters in figure 4, figure 5 and figure 5, it was found that clusters 2, 3 and 4 can be more clearly distinguished.

Table 3
The optimal number of clusters determined by the Hubert index, Hierarchical Clustering with Ward's minimum variance method (Ward D and Ward D2) and the Distance Matrix.

Methods	Optimal number of clusters
Hubert index	3
Hierarchical Clustering with Ward's method	2, 3, 4
Distance Matrix	3

Let's analyze the visualization of the results of dividing objects into groups based on Distance Matrix Computation (figure 7 and figure 8). As a result of analyzing the visual representation of the division of objects into groups, we can conclude that in figure 7, 3 groups of objects can be clearly distinguished, although some objects are located on the border of clusters 3 and 2. As a result of the analysis of the visual representation of the division of objects into 4 groups (figure 8), it can be concluded that cluster 2 can be more clearly distinguished, although there are objects that are located on the border of clusters 2 and 3, but the areas of clusters 1, 3 and 4 overlap. Based on the results of the analysis of the division of objects into groups based on Distance Matrix Computation, it can be recommended to divide the objects into 3 groups in the study.

Thus, it has been established that the optimal number of clusters into which it is recommended to divide the objects of the test results using the "Fedorets' Questionnaire for Determining Ecophilic Tendencies of Consciousness" in our study is 3 clusters (table 3).

In order not to lose the unique clusters of data that are grouped into respondent groups based on the results of testing using the "Fedorets' Questionnaire for Determining Ecophilic Tendencies of

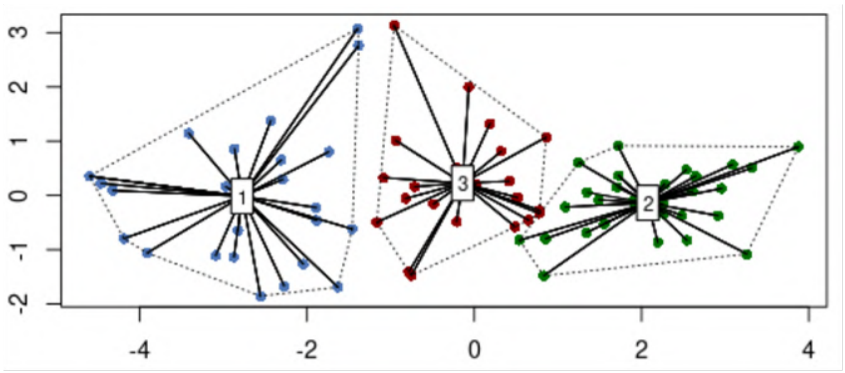


Figure 7: Visual representation of the results of dividing objects into 3 groups based on Distance Matrix Computation.

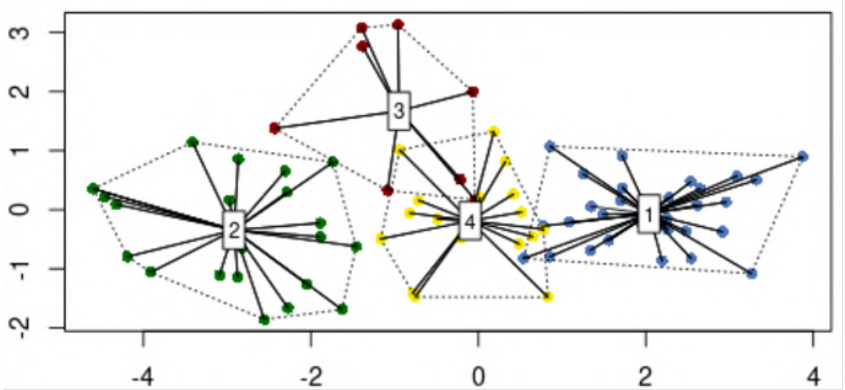


Figure 8: Visual representation of the results of dividing objects into 4 groups based on Distance Matrix Computation.

Consciousness" in accordance with the specific features of the degree of manifestation of ecophilic intentions and values, the number of clusters 3 and 4 was chosen for the study.

We will use the K-Means and Canopy methods to cluster objects. Let's analyze the results of dividing the data of the test results using the "Fedorets' Questionnaire for Determining Ecophilic Tendencies of Consciousness" into 3 clusters using the K-Means method. The results of dividing the objects into 3 clusters using the K-Means method are presented in table 4 and table 5.

Cluster 1 has the following centroids – 2, 2, 2, 2, 3, 3, 2, 3, 2, 2, 3. This cluster contains 30% of the data, which is 50 instances. The cluster indicates the presence of a rather stable ecophilic orientation of consciousness. Ecophilicity as a significant characteristic of consciousness has a high degree of intensity.

Cluster 2 has the following centroids: 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 1. The cluster was formed on the basis of the answers of 70 people (42%). The cluster represents a group of people who have an ecophilic orientation of consciousness with a low degree of intensity of manifestation, as well as those who have no or no ecophilic orientation of consciousness.

Cluster 3 has the following centroids: 2, 2, 1, 2, 2, 2, 2, 2, 2, 1, 1. The cluster contains 28% of the data, which amounts to 46 instances. The cluster reveals the presence of a rather stable ecophilic orientation of consciousness with a high degree of intensity of manifestation.

Let's analyze the results of dividing the data of the test results using the "Fedorets' Questionnaire for Determining Ecophilic Tendencies of Consciousness" into 4 clusters using the K-Means method. Table 6 and table 7 show the results of the distribution of objects into 4 clusters using the K-Means method presented in table 7.

The presence of a fairly significant set of objects – 28% of people forming Cluster 2, and, accordingly, having stable tendencies of ecophilic consciousness and the transitional group represented by Cluster 3 (5% of all respondents), which indirectly reflects the trend of development of ecophilic tendencies of consciousness, indicates the need to apply such strategies and technologies for ecologization, which include distinct aesthetic and worldview components. Accordingly, the actualization of the aesthetic and worldview level intellectualizes, aestheticizes, expands, deepens and interprets the existing deep lyophilic, existential and emotional and emotional perception of the planet Earth and nature as special values, meanings and images, transforming them into stereotypes of actions and behavior and

Table 4
Centroids of 3 clusters determined using the K-Means method.

Question number	Cluster 1	Cluster 2	Cluster 3
Q1	2	1	2
Q2	2	1	2
Q3	2	1	1
Q4	3	1	2
Q5	3	1	2
Q6	2	1	2
Q7	3	1	2
Q8	2	0	1
Q9	2	0	1
Q10	3	1	2

Table 5
Distribution of data by 3 clusters using the K-Means method.

Cluster number	Distribution of data by clusters
1	50 (30%)
2	70 (42%)
3	46 (28%)

Table 6
Centroids of 4 clusters determined using the K-Means method.

Question number	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Q1	2	2	1	1
Q2	1	2	2	1
Q3	1	2	2	1
Q4	2	3	1	1
Q5	2	3	2	1
Q6	2	2	2	1
Q7	2	3	2	1
Q8	1	2	1	0
Q9	1	2	1	0
Q10	1	3	3	1

Table 7
Distribution of data by 4 clusters using the K-Means method.

Cluster number	Distribution of data by clusters
1	70 (42%)
2	46 (28%)
3	8 (5%)
4	42 (25%)

psychological attitudes. Accordingly, this level of ecologization is called aesthetically harmonizing.

For the objects of Cluster 1 (42%) and Cluster 4 (25%), we consider the strategy of ecologization relevant, in which the leading aspect is the idea of harmonization aimed at "constructing" at the mental level a harmonious and existentially oriented interaction with the environment and revealing the cognition of the high meanings of Gaia (Earth) and biophilia. This is the initial condition for the further development of ecophilic tendencies of consciousness. We call this level of ecologization existentially harmonizing.

Let's analyze the results of clustering the objects obtained in the course of testing using the "Fedorets' Questionnaire for Determining Ecophilic Tendencies of Consciousness" based on the Canopy method. In the process of applying the Canopy method, the division of objects into 3 clusters did not give optimal results in terms of interpretation, so the study presents the division of objects into 4 clusters using the Canopy method (table 8 and table 9).

Let's analyze the results of clustering using an integrative humanitarian and environmental approach. Cluster 1 has the following centroids according to the answers to the test questions and question

Table 8
Centroids of 4 clusters determined using the Canopy method.

Question number	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Q1	1	3	1	2
Q2	1	3	1	2
Q3	1	1	1	2
Q4	1	3	0	3
Q5	1	3	1	2
Q6	1	3	1	1
Q7	1	3	1	2
Q8	1	3	0	2
Q9	1	3	0	2
Q10	1	3	1	2

Table 9
Distribution of data by 4 clusters using the Canopy method.

Cluster number	Distribution of data by clusters
1	76 (46%)
2	42 (25%)
3	36 (22%)
4	12 (7%)

numbers: 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1 (table 8). The algorithm assigned 76 data instances to the cluster, which is 46% of the answers. This cluster reflects the dominant group. At the same time, in this group, the dominant ecophilic intentions and values are characterized by the lowest degree of manifestation (or intensity). Therefore, we consider them unstable. Thus, despite the dominance of ecophilic tendencies of consciousness, but with low intensity, manifested in a significant quantitative representation in the specified cluster, it may indicate: a real but not yet sufficiently sustainable effect that has arisen due to the education and promotion of environmentally acceptable behavior and values, as well as a tribute to the fashion for "ecological behavior". Therefore, considering that in this cluster, which makes up almost half of the entire sample, this ecophilicism can be disaccommodated under the influence of certain factors (economic, political) under the influence of minor economic, psychological or socio-cultural influences. This indicates the need for targeted cultural and educational influences in order to develop ecophilic tendencies of consciousness.

Cluster 2 has the following centroids: 3, 3, 1, 3, 3, 3, 3, 3, 3, 3, 3 (table 8). This cluster contains 25% of the data, which is 42 instances. The cluster reveals a rather stable ecophilic orientation of consciousness with a high degree of intensity of manifestation. One fourth of the individuals in the study sample to some extent reflects the attributive features of a human being as a highly developed intellectually and morally species characterized by love and good attitude towards the world and living beings. That is, this number can to some extent be interpreted as a manifestation of human nature, which has an ecophilic nature, and not only and not so much the influence of education and society.

Cluster 3 was formed on the basis of the following centroid answers to the questionnaire: 1, 1, 1, 1, 0, 1, 1, 1, 0, 0, 1. The cluster was formed on the basis of answers of 36 people (22%). The cluster represents a group of people who have both an ecophilic orientation of consciousness with a low degree of intensity of manifestation and people who have no or low level of ecophilicity. Almost a quarter of the sample reflects a variety of reactions, which includes both minor ecophilic tendencies and their absence. This, to some extent, as well as the previous Cluster 1, illustrates the specifics of the distribution of traits in the population. That is, there is a group characterized by quite pronounced ecophobic tendencies (25%) (Cluster 2) and, to some extent, the opposite group of people with insufficiently pronounced and/or absent ecophilic tendencies (22%) (Cluster 3). The risk of people in this group (Cluster 3) is that they may transform into ecophilic neutrals or ecophobes as a result of external influences.

Cluster 4 is based on the following answers to the questionnaire: 2, 2, 2, 2, 3, 2, 1, 2, 2, 2, 2, 2. This cluster combines the answers to the questions of 12 people and makes up 7%. This cluster unites people who have both distinct ecophilic tendencies of consciousness (answer – 3, 2) and relatively non-intense ones (answer – 1). We consider it a "transitional" cluster between Cluster 1 and Cluster 2. This is due to the fact that it contains features of both of these clusters (Cluster 1 and Cluster 2). Cluster 4, which is transitional and relatively significant in quantitative terms (7%), reflects an important trend – the active dynamics of the formation of ecophilic consciousness under the influence of socio-cultural (including educational) factors, which is caused by global processes of ecologization.

The presence of a relatively large group of 25% of people who form Cluster 2 and, accordingly, have stable tendencies of ecophilic consciousness and the transitional group represented by Cluster 4 (7% of all respondents), which indirectly reflects the trend of development of ecophilic tendencies of consciousness, indicates the need to apply such strategies and technologies for ecologization, which include distinct aesthetic and worldview components. We call this level (or aspect) of ecologization

aesthetically harmonizing.

For the representatives of Cluster 1 (46%) and Cluster 3 (22%), we consider the strategy of ecologization relevant, in which the leading aspect is the idea of harmonization aimed at "constructing" at the mental level a harmonious and existentially oriented interaction with the environment and cognition of the high meanings of Gaia (Earth).This is the initial condition for the further development of ecophilic tendencies of consciousness. We call this level (or aspect) of ecologization existentially harmonizing.

The above cluster model, like the previously discussed one, with the formation of 4 clusters, contributes to the structuring of ecologization as an educational meta-strategy with the allocation of two levels (or directions) in it – existentially harmonizing and aesthetically harmonizing.

A comparative analysis of the cluster models obtained by applying the K-Means and Canopy methods (table 6 and table 7, table 8 and table 9) shows quite similar results. The similarity is manifested in the structure of the distribution by clusters and in the architecture of the clusters themselves, which indicates the correctness and adequacy of the methods used. These two cluster models, in which objects are structured into 4 clusters, complement and extend the cluster system obtained by applying the K-Means method with a division into 3 clusters.

We consider the above aspects of ecologization – existentially harmonizing and aesthetically harmonizing – to be complementary and view them as independent paths or as successive stages. We consider the existentially harmonizing aspect of ecologization to be related to the coexistence of man and the Earth ("natural existence"). This aspect is understood as aimed at revealing the understanding of oneself as: an integral part of the Earth's space; the Earth as a home, the value of Earth's landscapes, elements and "kingdoms" (minerals, animals and plants); a sense of oneself as a spatial being harmonized with Earth's landscapes.

The aesthetic and harmonizing aspect of ecologization is based on the dominant aesthetic dimension, within which the Earth and Earth landscapes, elements and "kingdoms" of plants and animals are understood as: a special natural earthly and cosmic harmony and aesthetics ("natural beauty"); as an aspect of inspiration. This aspect is understood not as "pure" creativity or aestheticism, but as an aesthetic intention aimed at preserving the Earth. These aspects (existentially harmonizing and aesthetically harmonizing) can be presented in greening strategies in a more distinctive or integrated way.

The results of the study of ecophilic tendencies of consciousness are used to formulate and implement strategies and practices of greening, as well as to develop environmental competence and soft skills in the educational process of higher education, including education in the field of information technology, teacher training, and postgraduate education.

Let us consider examples of strategies for applying the results of the study to the ecologization of university students. For the greening of future teachers of mathematics and computer science and students of information technology, the primary is the actualization of the rational dimension of consciousness, which primarily includes the disclosure of the harmony and beauty of the world through ecological and aesthetic reflection on mathematical, information and environmental phenomena and works of art. That is, the aesthetic and harmonizing direction of ecologization is primary as "external" (aimed at cognition of the external world), the actualization of which subsequently contributes to the manifestation of the existential and harmonizing direction, which is essentially internal. This approach to ecologization is inherently both intellectualized and aestheticized. An important aspect of the disclosure of the student's ecological knowledge and intellectual potential is mathematical and informational knowledge and ideas that illustrate and reveal ecological phenomena at the level of mathematical rationality. In this case, mathematical knowledge and information algorithms act as procedural and operational ones, which, being part of environmental knowledge, make it possible to represent and comprehend environmental phenomena and represent them as regularities, processes, harmony, disharmony, compliance or non-compliance with certain aesthetic and environmental "ideals". The specificity of ecological knowledge is also that it is formed as ethically and value-oriented, not as irrelevant or "ethically and aesthetically neutral". The value, ethical and aesthetic orientation of environmental knowledge is largely determined by its procedural and operational components, which in turn reflects primarily its mathematical and informational dimensions (both in actual, formalized and contextual formats).

In order to develop the health-preserving competence of physical education teacher in postgraduate education, namely the formation of its anthropocultural component, in the system of which the ecological aspect is defined as significant, we apply both existentially harmonizing and aesthetically harmonizing directions of ecologization. The existentially harmonizing direction of ecologization is especially important, the possibility of realization of which is determined by existential specificity of motor activity and the possibility of actualization of existentials of corporeality, spatiality, temporality in the process of physical culture. This direction is largely reflexive, existential and cognitive, internal (directed at oneself) and introverted (largely directed at oneself and self-knowledge) and contextual, as well as connected with the subconscious dimension of the psyche and the collective unconscious. Accordingly, this direction is realized by means of physical culture and can be formally represented as "Cognition and dialogue with the planet Earth through physical activity, mastery of the landscape and self-knowledge". The aesthetically harmonizing direction is dominated by external, extroverted (directed to the outside world), emotional and cognitive orientation. It is both rational and emotional, and accordingly, it is revealed and realized through the cognition of earthly landscapes in the process of moving in space and through the actualization of visuality and visual culture. That is, physical culture reveals the aesthetics of the outside world through motor activity, while additionally using the means of art.

4. Discussion

Let us consider the work of some researchers in relation to our scientific developments.

The use of cluster analysis to identify groups of students who differ in specific, group-specific characteristics is a technique that we have used effectively in many studies, including the Canopy method [24]. Also, for example, Galati et al. used fuzzy clustering methods to study students' behavior in purchasing products in environmentally friendly packaging [10].

The use of mathematical statistics methods, according to many authors, is appropriate for studying environmental awareness [7, 14, 24], and our results confirm that determining the level of "environmental potential" will make it possible to outline the directions of its formation and development. In particular, the results of our research on recommendations for increasing the level of ecophilic consciousness correlate with the results of other researchers, in particular, with the study of Lian et al. [11], Mulrow et al. [9], Arya and Kumar [12] that it is necessary to raise students' awareness of the environment in order to better understand the risks.

Saboya de Aragão and Alfinito [4] point out the insufficient understanding of the relationship between human values and environmental behavior of consumers. Comparing the ideas presented in this study with our findings, it can be noted that the existential and harmonizing aspect of greening identified by us can be considered as a strategy for shaping consumer environmental behavior based on the actualization of human values.

Pu et al. [5] studying the impact of COVID-19 on environmental sustainability and development, identify the qualities of creativity, innovation, altruism, and compassion. We consider these qualities to be cognitive, behavioral and emotional prerequisites for the ecophilic orientation of a personality, as well as cognitive and behavioral factors of the existential and harmonizing aspect of greening.

Zhen, Yue and Yulong [6], who study the formation of ecological physical education of college on the basis of actualization of multidisciplinary approach consciously or intuitively deal essentially with the development of ecophilic tendencies of consciousness (orientation, values, etc.). This indicates the conceptual proximity of these studies.

Peters [39], who proposes to integrate artificial intelligence technology and environmental design to improve the quality of urban space, develops his concept in relation to the aesthetic and harmonizing strategy (or aspect) of greening that we have identified. Peters [39] and Brien [40] essentially proposes to integrate the aesthetic and environmental (in the format of ecodesign) and cognitive, which largely corresponds to the ideology of NBIC-convergence, which corresponds to the 6th technological mode.

Arya and Kumar [12], based on the application of the theory of normative value behavior to study

the environmental behavior of university students, conclude that the presence of altruistic and egoistic values and responsibility significantly predict pro-environmental behavior. These ideas of Arya and Kumar [12] correlate with the existential harmonizing aspect of ecologization presented by us, which can also be considered as a strategy. Within the framework of the existential harmonizing aspect of ecologization, the actualization of existential values and relevant types of behavior and behavioral stereotypes (and character traits; more broadly, according to A. Paccei, human qualities), namely altruism and responsibility, is crucial. In this aspect, it is significant that the phenomenon of responsibility is one of the central ones in the existential approach. The presence of responsibility indicates the existential completeness and maturity of the individual and his/her ability to form ecological meanings that are lived and understood in a deep and existential way – as existential meanings. Accordingly, this determines environmental or pro-environmental behavior.

5. Conclusion

The anthropological and psychological basis for the implementation of the Sustainable Development Goals is the development of relevant ecologically oriented human qualities, which are a prerequisite for ecologically oriented behavior. This study emphasizes the importance of the existential and harmonizing aspect of ecologization, which can be presented as a purposeful strategy.

The overarching idea of the research is the study of psychological, value, cognitive and behavioral factors in the development of environmental consciousness and human behavior. The psychological prerequisite for the formation of these human qualities is the ecophilic tendencies of consciousness, which determines the need for their digital and mathematical modeling using systems of methods. In the study, we used the methods of system analysis, cluster analysis, methods of mathematical statistics, digital modeling, digital data visualization, etc.

In order to determine the optimal number of clusters, we used the Hubert index and its graphical representation, hierarchical clustering with Ward's minimum variance method (Ward D and Ward D2) and its visual representation, distance matrix and visualization based on it. Using these methods, it was diagnosed that the optimal number of clusters is 3 clusters. However, in the course of the study, we decided to divide the set of objects into 4 clusters in order to lose the unique structure of the cluster for diagnosing the ecophilic intentions and values of university students.

We clustered the objects using two clustering methods – K-Means and Canopy. The use of these two methods is justified by the structure and types of data and the features of the algorithms. Based on the results of clustering using these two methods, cluster models were formed. The obtained models for dividing objects into 4 clusters are similar, which indicates the effectiveness of the K-Means and Canopy algorithms with such data structures and confirms the adequacy of the constructed cluster structures.

Based on the study of ecophilic tendencies of consciousness using cluster modeling with the help of K-Means and Canopy methods, the 3rd and 4th clusters were formed. In our opinion, 4 cluster models are more representative clustering models. These models are dominated by clusters with a slight development of ecophilic tendencies of consciousness (42-46%). The "ecophilic" clusters (25-28%) with a medium and high level of ecophilic tendencies of consciousness is defined as the system-organizing one. In quantitative terms, this feature is quite significant, indicating the formation of a "stratum" of modal individuals who are active "carriers" of the ecological idea, which is relevant for socio-cultural ecological transformations. The "transitional" clusters (5-7%) is also identified, which indicates the presence of "ecological potential" in the cluster with the lowest level of ecophilic tendencies of consciousness. The presence of this clusters, which is determined by structuring into 4 clusters using different methods, also reflects the effectiveness of existing educational and cultural influences aimed at ecologization. This structure of clusters also reflects the presence of humanistic and democratic traditions in the system of which ecologization is implemented in a "soft" intellectualized way, aestheticized as a cultural and educational trend, and not as an indoctrination of an ideological doctrine. This is in line with the ideology of the Sustainable Development Goals aimed at unlocking human potential.

University students are a dynamic and socially active group and, accordingly, they can act as agents

of environmentally oriented changes in the socio-cultural, professional and scientific dimensions. Therefore, an important social and socio-psychological aspect of modeling ecophilic tendencies of consciousness is the analysis of the formation of these tendencies in university students with the corresponding development of ecologization strategies. The results of the study of ecophilic tendencies of consciousness are taken into account in the development of strategies for the ecologization of higher education students. Two directions of ecologization are conceptualized, which can be simultaneously represented at the same level – existentially harmonizing and aesthetically harmonizing.

The existentially harmonizing direction of ecologization is largely reflective, existentially cognitive, internal (directed at oneself) and introverted (largely directed at oneself and self-knowledge) and contextual, as well as connected with the subconscious dimension of the psyche and the collective unconscious. The aesthetically harmonizing direction is dominated by external, extroverted (directed to the outside world), emotional and cognitive orientation. It is both rational and emotional. At the methodological and metacognitive levels, the process of ecologization is structured on the basis of the above directions (existentially harmonizing and aesthetically harmonizing) and is used to develop ecophilic tendencies of consciousness, in particular, of future mathematics teachers, students of information technology and to improve the health-saving competence of physical education teachers, in the system of which the ecological aspect is a significant factor for health preservation.

Declaration on Generative AI: The authors have not employed any Generative AI tools.

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Harnessing immersive technologies for enhancing Japanese language acquisition: Methodological insights for prospective language educators

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Abstract

This article explores the methodological aspects of leveraging immersive technologies to facilitate Japanese language acquisition for prospective language educators. The study analyses the application of virtual and augmented reality in supporting and organising Japanese language learning for aspiring language teachers, and identifies the primary approaches to employing augmented reality in language education. The findings suggest that immersive technologies introduce a novel paradigm for educational materials, positively influencing the development of fundamental and professional competencies in future Japanese language educators. These technologies can be particularly effective when integrated into a blended learning model that combines distance, online, traditional, and self-directed learning of Oriental languages. The study highlights the need for further research to develop guidelines for utilising immersive technologies in teaching Oriental languages at various stages of language teacher training.

Keywords

immersive technologies, augmented reality, virtual reality, Japanese language acquisitionv prospective Japanese language educators, blended learning, oriental language learning, distance education

1. Introduction

The rapid advancement of information and communication technologies (ICTs) and their pervasive integration into various domains of human activity necessitate the adaptation of young individuals to novel modes of working, living, and interacting. Contemporary technologies, employed across diverse professional fields, hold immense significance for incorporation into the educational process, particularly within general education institutions, and are crucial for the competitiveness of youth in the global job market.

In this context, immersive technologies (ITs) are gaining increasing popularity in the education sector [1, 2, 3]. These technologies, which extend reality or create new realities by harnessing the 360° space, are exerting a profound influence on numerous facets of 21st-century life, including commerce, tourism, the interaction with and perception of digital information and media, science, and education [4, 5, 6, 7]. Makransky and Petersen [8] emphasise that the application of these technologies can enhance real-world visualisation through the incorporation of virtual objects, graphics, and object recognition technologies.

ITs encompass virtual reality (VR), augmented reality (AR), and mixed reality (MR), which are currently being employed in a wide array of fields, ranging from gaming and entertainment; theatre and live events; museums and cultural heritage; marketing, advertising, and tourism; architecture, product development, and design; to simulation and healthcare [9, 10, 11, 12, 13, 14].

While ITs are predominantly utilised in science education to cover topics such as human anatomy (Anatomy AR-VR, AR Human Anatomy, The Brain AR App, etc.), the universe (Planets AR, EARTH AR Poster, etc.), chemical reactions (MoleculAR, Chemistry Augmented Reality Education Arloon, etc.), and plant anatomy (Froggipeadia, Arloon Plants AR, etc.), this paper focuses on their role in

AREdu 2024: 7th International Workshop on Augmented Reality in Education, May 14, 2024, Kryvyi Rih, Ukraine
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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

CEUR-WS.org/Vol-3918/paper058.pdf

foreign language education, specifically in the context of Japanese language learning. Given the limited availability of applications and IT content tailored for language education, we will explore all potential applications of ITs (VR and AR) in Japanese language acquisition and the experiences of students.

2. Theoretical backgrounds

The multifunctionality of ITs and the unfamiliarity of the concept of "virtual reality" have catalysed the actualisation of the term "virtual" and the rapid expansion of its scope, serving as an impetus for the conceptual design of the idea of virtual reality across various domains of human activity.

AR holds immense potential in the field of language education [15, 16], as it serves two primary functions: contextual visualisation (i.e., the presentation of virtual information within an extended context) and interactivity of learning (i.e., the embodiment of interaction with virtual content). VR, on the other hand, is a virtual 3D world that enables users to experience visual simulations and feel immersed in an environment free from temporal and spatial constraints.

The popularisation of the phrase "virtual reality" can be attributed to Jaron Lanier in the late 1980s [17].

At the current stage of ICT development, immersive technologies based on VR can be categorised as follows (figure 1):

- VR with full immersion, which provides a realistic simulation of the virtual world with a high degree of detail (e.g., the Virtual Shooter game zone);
- Partial immersion VR, consisting of VR and real-world attributes, is achieved by embodying computer graphics objects in a reality scene (e.g., a flight simulator) [18];
- VR without immersion, related to the virtual experience with a computer, where users can control individual characters or their actions in the software, while the environment does not directly interact with the user (e.g., World of WarCraft, ReHabgame);
- VR with group work, which represents a three-dimensional virtual world with elements of a social network (e.g., Minecraft already has a version of virtual reality supported by Oculus Rift and Gear VR helmets) [19];
- CAVE (Cave Automatic Virtual Environment), developed by students at the University of Illinois in 1995, is a three-dimensional stage with wall projections [18, 20].

The term "Augmented Reality" was coined by aircraft engineers Caudell and Mizell [21] in 1990. They developed head-mounted displays as equipment for electricians to be used during the assembly of complex wiring harnesses [22].

Nelson [23] identifies augmented reality as an essential element of the "Bring Your Own Device" (BYOD) approach, which entails the use of mobile devices by teachers and students in the classroom for learning purposes.

Calo et al. [24] define Augmented Reality as "…a mobile or embedded technology that senses, processes, and outputs data in real-time, recognises and tracks real-world objects, and provides contextual information by supplementing or replacing human senses."

AR is a technology that incorporates digital information such as images, video, and audio into real-world spaces, enabling the blending of virtual environments with reality [25]. Users of this technology have the opportunity to learn in immersive, computer-generated environments through realistic sensory experiences.

Mobile AR applications can be grouped into three categories based on their purpose, place of use, and usability: marker-based, creation-based, and marker-less AR (figure 2).

It is worth noting that some applications in these categories may possess both creation-based and marker-less features. However, if an application is marker-based, it cannot have a marker-less AR feature, as it could only function with flashcards.

We can distinguish the following types of mobile AR [26]:

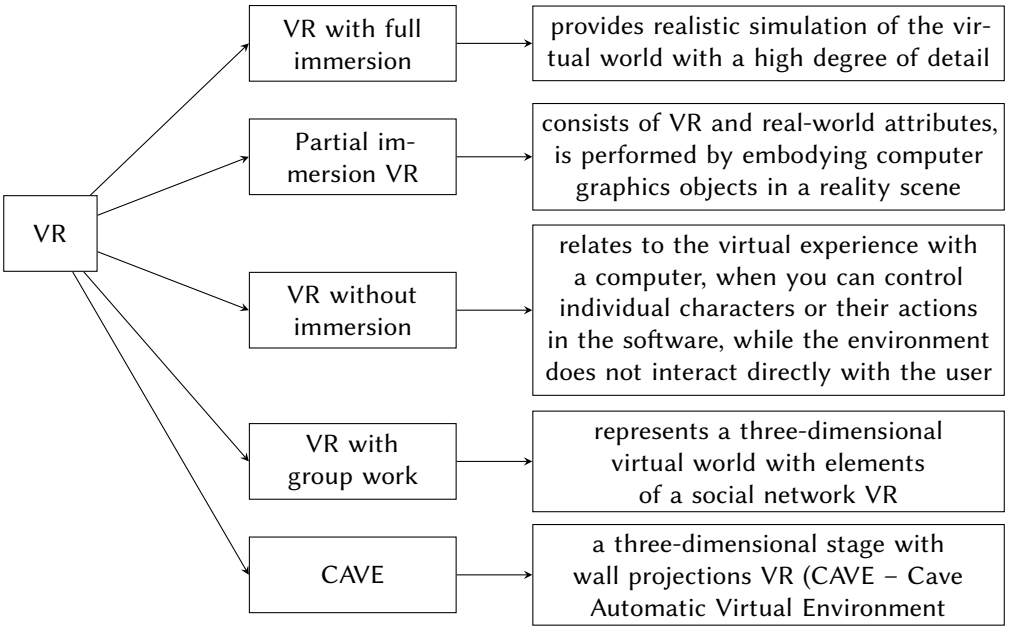


Figure 1: The five categories of VR.

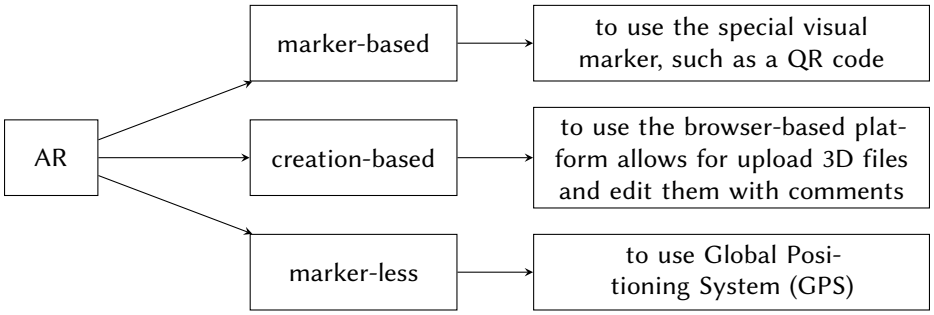


Figure 2: The three categories of mobile AR.

- marker-based, which uses a camera and a special visual marker, such as a QR code (quick response code);
- creation-based, which uses a browser-based platform allowing users to upload 3D files and edit them with comments, detailed instructions, and animations via a drag-and-drop interface;
- marker-less, which uses the Global Positioning System (GPS); the most common uses are to mark destinations, search for the correct location, such as a café or office, or in location-oriented applications.

Researchers have identified several positive effects of AR on students' foreign language learning, including enhancing the effectiveness of their language skills in professional translation, increasing motivation to learn, and engaging students in collaboration with each other and with native speakers of the foreign language being studied [27, 28, 25, 29, 8, 30, 31, 19, 23, 32]. AR has immense potential in the field of language education due to its functions of contextual visualisation (i.e., the presentation of virtual information within an extended context) and interactivity of learning (i.e., the embodiment of interaction with virtual content).

A review of the literature by Viberg and Grönlund [33] indicates that Mobile Assisted Language Learning (MALL), as a mobile technology that can be adapted to support language learning, is applied in various ways but generally focuses on vocabulary acquisition, listening and speaking skills, and language acquisition, while grammar learning, pronunciation, and writing skills were underrepresented in the application of MALL.

Hein et al. [34] analysed 2,507 sources and selected 54 articles published between 2001 and 2020 that related to the role of immersive technology in students' foreign language learning.

They found that most of these studies focused on the comparative analysis of traditional blended learning methods, which included the use of VR and AR. The main characteristics of these technologies that support foreign language learning are the promotion of vocabulary learning, the development of speaking skills and intercultural competence, students' motivation for foreign language learning, and the ability to overcome anxiety and discomfort when communicating in a foreign language. The advantage of learning with AR over traditional teaching methods lies in the fact that students are given the opportunity to feel, rather than imagine, the subject, situation, or scenario, which cannot be demonstrated or described using traditional teaching methods.

The purpose of this article is to analyse the use of immersive technologies for supporting and organising Japanese language learning for prospective language teachers and to identify the main approaches to the use of immersive technologies in Japanese language learning.

3. Research methods

To achieve the purpose of our study and clarify the problem of utilising immersive technologies for prospective Japanese language teachers, we employed the following methods: systematic and comparative analysis of pedagogical, psychological, philosophical, sociological works, methodological and specialised literature; analysis of the pedagogical experience of using immersive technologies at the Institute of Philology of Taras Shevchenko National University of Kyiv in lectures and seminars on "Japanese characters"; synthesis and generalisation to formulate the main points of the study; interpretation of the research results through a student survey and comparative analysis of exam results in Japanese lexicology of students who studied the language using ICT and immersive technologies with exam results of students who studied the language using ICT but not immersive technologies. The research hypothesis is based on the assumption that the training of prospective Japanese language teachers will be effective if the following pedagogical conditions are implemented: activating the motivation of future foreign language teachers to carry out project activities using immersive technologies as didactic tools for learning Japanese; improving the content of training future foreign language teachers to form their knowledge about the use of information and communication technologies and immersive technologies for learning Japanese.

4. Results and discussion

Scientists attach special importance to the use of augmented reality in the study of Oriental languages by students, particularly prospective teachers of the Japanese language.

They note that the preparation of prospective teachers of Oriental languages (including languages with character-based writing, such as Japanese and Chinese) for professional activities is a complex process, as it differs significantly from the study and teaching of any other foreign language (for instance, English, French, German, Italian, Spanish, Turkish languages that are also included in the educational planning of the Institute of Philology of Taras Shevchenko National University of Kyiv).

Researchers recognise the use of ITs as a solution to the problems of fast, active, correct, and convenient Oriental language learning by students [27, 25, 29, 8, 30, 23]. They note that the use of these technologies can improve real-world visualisation with virtual objects, graphics, and object recognition technologies.

Frazier et al. [29] highlights the application of Google Earth VR and AR for foreign language learning, including Japanese, which allows users to visit different locations throughout the world, while simultaneously supporting their own learning of various subjects, such as history, political studies, international relations, etc.

Google Earth AR includes numerous instruments, like Mindshow, for the creation of new exciting places and their use in role-playing [23]. This tool is marker-less and uses GPS. Scientists focus their

Table 1
The results of students' survey on their understanding of ITs in Japanese language learning process (2020-2021).

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
I have a clear understanding of what ITs are and how they can be integrated into my own education process	8%	17%	32%	39%	4%
I have heard about ITs in foreign language learning	3%	16%	28%	49%	4%
I have discussed ITs for foreign language learning with my friends	18%	35%	14%	33%	0
I have experience with teachers using approaches with ITs for Japanese language learning	8%	43.6%	35.5%	12.7%	0
Total ($N = 31$)					

attention on the issue that these instruments are useful for distant language learning, although they should be supervised by a teacher.

We should pay attention to the possibility of foreign language learning, particularly Japanese, with the help of this service and others that focus on various fields of science in Japanese.

It is important to emphasise the potential of augmented reality services that support the teaching of various disciplines. Special emphasis should be placed on training in the fields of STEM education, which involves integration between the disciplines of natural sciences, technological sciences, engineering, and mathematics [26, 35, 36]. For example, many augmented reality applications offer materials in Japanese (BioDigital Human 3D anatomy, 3D Anatomy Learning – Atlas, GeoGebraAR, Planets AR, etc.). It is clear that the vocabulary of these applications is designed for students who have language skills at the B1 level and above.

Geng and Yamada [30, 31] offer their experience of using AR generators to create markers based on Kanji characters as QR codes. They developed an AR compound verb learning system to support the learning of Japanese verbs. Under this system, students can scan a card with the Kanji characters of a particular verb and watch an animation that displays the corresponding action with the card through the smartphone screen in the application. "In this system, the meanings of verbs, including both single verbs and compound verbs, were represented by 3D animations created using Maya, according to the image schemas of the verbs. Maya is a 3D computer graphics software, and it is used to create interactive 3D animations and visual effects". The application was developed by scientists using Unity 3D and Vuforia. In addition, the combination function was proposed based on a combination of two cards with the corresponding Kanji characters (V1 + V2) to facilitate the effective study of complex verbs by students. Researchers have proven that the approach involving AR in Oriental language learning is the most effective for students compared to the traditional method.

Platte et al. [37] suggests using ARTranslate (https://github.com/benpla/ARTranslate) for foreign language learning using augmented reality. ARTranslate is software that recognises up to 1,000 objects in a user's environment using the Convolutional Neural Networks (CNN) method and names them accordingly. Objects are superimposed on 3D information in different languages using AR. The user can access the surrounding everyday objects in any language by switching languages in the ARTranslate application settings. The software runs on iOS version 12.

We surveyed students (31 students participated in this survey) about their attitudes towards the use of ITs to improve the quality of Japanese language learning. We proposed the following statements, which students should designate as "Strong disagree", "Disagree", "Neither agree", "Agree", or "Strongly agree": "I have a clear understanding of what ITs are and how I can integrate them into my own education process", "I have heard about ITs in foreign language learning", "I have discussed ITs for foreign language learning with my friends", "I have experience with teachers using approaches with ITs for Japanese language learning".

According to the questionnaire analysis of students' attitudes and understanding of ITs in the Japanese language learning process, it was found that students understand what augmented reality is but have not used these tools to learn Japanese: "I have a clear understanding of what ITs are and how they can be

integrated into my own education process": Strongly disagree – 8% students; Disagree – 17% students; Neither agree nor disagree – 32% students; Agree – 39% students; Strongly agree – 4% students; "I have heard about ITs in foreign language learning": Strongly disagree – 3%; Disagree – 16%; Neither agree nor disagree – 28%; Agree – 49%; Strongly agree – 4%.

We showed students the options for using such IM for different levels of Japanese language learning (Japanese language learning levels are available at https://www.jlpt.jp/) as:

- ITs for not language learning such, as BioDigital Human 3D anatomy, 3D Anatomy Learning – Atlas, GeoGebraAR, Planets AR, Google Earth AR and VR;
- ITs for language learning such, as Easy Japanese News, Triplens, ARTranslate;
- Platforms for creating web projects with AR elements such, as BlippAR and Google ARCore, and with VR such, as CoSpaces, for students to create their own examples of language learning.

These tools were proposed for use by 3rd year Bachelor's students in the study "Japanese Kanji characters", 4th year Bachelor's students in the study "Linguistic Tradition of Japan", 4th year Bachelor's students in the study "Japanese Language Etiquette", 2nd year Bachelor's students in the study "Japanese language: Practical Course for Translators", and 1st-2nd year Bachelor's students in the study "Oriental Language (Japanese language)" of the Department of Languages and Literatures of the Far East and Southeast Asia of the Institute of Philology of Taras Shevchenko National University of Kyiv.

After classes and self-study of students with the help of ITs, a survey was conducted as experts (27 students) on the choice of approaches to the study of Japanese characters. They were asked to use the Likert Scale method to rank approaches to language learning according to their importance – from ineffective (1 point) to very effective (5 points).

Approaches to the study of Japanese Kanji characters were determined according to traditional methods (direct method, grammar-translation method, audio-lingual method, cognitive method) and considering the use of information and communication technologies, in particular immersive technologies.

Our students were offered the following approaches to Japanese Kanji (漢字) learning for the assessment:

- use of electronic dictionaries;
- search and use of Internet resources;
- usage of online educational literature;
- creation and application of their own associations (offline);
- handwriting Kanji characters (offline);
- use of AR and VR applications;
- creation of their own educational materials on the basis of ITs.

The results of this questionnaire are presented in table 2 "Results of students' questionnaires on their opinion on the choice of approaches to the Japanese Kanji characters learning".

Thus, the results of students' questionnaires about their opinion on the choice of methods for studying Japanese Kanji characters showed that the most necessary approach for them was based on the creation of students' own learning materials using augmented reality (5). According to interviews with students who wished to comment on their answers, this was motivated by the creation of augmented reality Kanji characters that would be of interest to other students and reflect the most difficult cases in Oriental language translation practice. The use of electronic dictionaries (4.8) is also important, as most AR applications are focused on the assimilation of foreign language vocabulary by users (for example, Triplens, ARTranslate, etc.).

To achieve our goal, we created, organised and implemented educational content (training course) "Information Support of Philological Research in Japanese Studies" for philology bachelor's students of Oriental languages, based on the use of immersive technologies. It consists of the following modules: Module 1 "Theoretical foundations of the use of ICT in the study of foreign languages", covering topics such as "Basic concepts", "Methods of using ICT in the study of foreign languages", etc.; Module 2

Table 2
Results of students' questionnaires on their opinion on the choice of approaches to the Japanese Kanji characters learning.

The approaches to Japanese Kanji (漢字) learning	Mean values
use of electronic dictionaries	4.8
search and use of Internet resources	4.4
usage of online educational literature	3.2
creation and application of their own associations (offline)	2.9
handwriting Kanji characters (offline)	4.7
use of AR applications	3.8
use of VR applications	3.7
creation of their own educational materials on the basis of augmented reality	5

"Electronic educational resources for learning a foreign language (Japanese)", which covers topics such as "Electronic dictionaries and their practical use in translation and teaching", "Online tests in foreign languages: the use of international test systems and the creation of personal tests using web services"; Module 3 "Immersive technologies of learning a foreign language (Japanese)", which covers such topics as "Model of learning a foreign language using virtual reality", "Model of learning a foreign language using augmented reality"; Module 4 "Research activities on the establishment of Electronic Educational Resources for the translation and teaching of Japanese".

Students were divided into groups according to their desire to learn language using ICT, including immersive technologies, which are present in separate modules of the course "Information Support of Philological Research in Japanese Studies", which is part of a series of linguistic disciplines that form the philological basis of the bachelor's program at the Institute of Philology of Taras Shevchenko National University of Kyiv in different lectures and seminars.

In response to the question "Do you want to learn a language using immersive technologies?", 21 students answered, while 8 students did not take an active part in the survey and training due to extreme conditions (military action in Ukraine). As a result of the survey, two groups were created: 11 students who will study language using ICT and immersive technologies, and 10 students who will study language using ICT but not immersive technologies. The group of students studying the "Japanese language and literature" course using ICT and immersive technologies passed the exam with an average of 95 points, while the group of students that studied language using ICT but did not use immersive technology passed the exam with an average of 85 points.

5. Conclusions and prospects for further research

In conclusion, immersive technologies provide a new paradigm for the presentation of educational materials, positively impacting the formation of fundamental and professional competencies in prospective Japanese language teachers. We can identify the following benefits of using ITs to train future teachers of the Japanese language:

- the use of ITs makes the learning process more visual and mobile;
- the use of ITs increases students' interest and motivation to learn the language;
- ITs improve the learning process by incorporating innovative forms of student engagement;
- ITs create conditions for the formation and development of students' creative abilities;
- these technologies and approaches contribute to the support of the linguistic and cultural aspect of student learning.

The following approaches to the use of ITs for the study of Japanese by students should be distinguished: 1) the use of specialised applications for language learning; 2) the use of applications for studying other disciplines (anatomy, biology, computer science, astronomy, etc.) while simultaneously

learning a foreign language; 3) the creation of personal examples by students for learning a foreign language with the help of special web platforms.

ITs can be effective when used in blended learning that combines distance, online, traditional, and self-directed learning of Oriental languages.

The author plans to continue the longitudinal research, analysing the statistical data of students' academic performance and expanding the research to several other subjects (taught at Taras Shevchenko National University of Kyiv) during the academic year 2022-2023.

Prospects for further research include the creation of guidelines and manuals on the use of immersive technologies for the study of prefabricated languages at different levels of training for prospective teachers of the Japanese language.

Declaration on Generative AI: The authors have not employed any Generative AI tools.

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Harnessing immersive technologies for enhancing mathematical logics education in secondary schools

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Abstract

The majority of information that individuals perceive throughout their lifetimes is received through the perception of visual images, a rule that applies to the performance of any activity. Consequently, failing to consider the visual presentation of new knowledge during the learning process, as well as its quality, can hinder new generations from receiving a quality education. Considering current realities and demands on knowledge, skills, and abilities acquired during training, the issue of using high-quality visual educational content is closely linked to the development and use of information and communication technologies. This work examines and analyses the current state of the use of immersive technologies in education and explores the possibilities and specifics of employing virtual worlds in the educational process. Practical results of approbating virtual tools in the educational process are provided. A pedagogical experiment aimed at determining the effectiveness of immersive technologies in the context of the Ukrainian education system has been initiated.

Keywords

mathematical logics, immersive technologies, learning tools, virtual worlds, gamification, secondary education

1. Introduction

The tendencies of modernisation in education are influenced by globalisation processes worldwide, labour market needs, and external factors such as the quarantine caused by COVID-19 [1]. In light of this, the digitalisation of the education system opens up numerous prospects for enhancing the quality of the educational process [2]. Consequently, under the conditions of the rapid development of information and communication technologies (ICT), the teaching methods in general education schools are evolving.

For many years, teachers have been utilising videos during classroom lessons to present the theoretical component of new material. Currently, the flipped classroom approach is gaining popularity, the implementation of which is not possible without the use of educational information based on video. However, an increase in the level of learning through electronic educational resources in the form of videos in the "Let's Plays" genre cannot be observed. It is worth noting that unlike previous generations of students who interacted with websites, blogs, and educational channels based on social media, the current generation learns more through YouTube Let's Plays and Twitch-based video streams [3]. The present younger generation does not use books, web pages, or any of the technologies traditionally employed by older individuals.

The formation of a new format of digital literacy is necessary for the participation of young people in these predominantly special educational environments [4]. Firstly, it involves the ability to record and edit videos, "capture" and broadcast gameplay and other on-screen activities, a high level of technical communication, and the capacity to inform and teach others by performing complex tasks. The so-called immersive technology, which integrates the virtual environment with the physical environment,

AREdu 2024: 7th International Workshop on Augmented Reality in Education, May 14, 2024, Kryvyi Rih, Ukraine
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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

CEUR-WS.org/Vol-3918/paper078.pdf

becomes relevant, allowing users to naturally interact with mixed reality, encompassing two main types of reality: augmented (AR) and virtual (VR) [5, 6].

In today's rapidly evolving digital landscape, the integration of immersive technologies into the educational process holds immense potential for transforming the way we teach and learn [7, 8]. This is particularly true in the realm of mathematical logics, a subject that often poses challenges for students in secondary schools. By harnessing the power of virtual and augmented reality [9], educators can create engaging, interactive, and visually stimulating learning experiences that demystify abstract concepts and foster a deeper understanding of logical reasoning.

This research aims to explore the current state of immersive technologies in education, examine the possibilities and specifics of employing virtual worlds in the learning process, and present practical results of approbating virtual tools in the classroom. Furthermore, a pedagogical experiment has been initiated to determine the effectiveness of immersive technologies within the context of the Ukrainian education system.

2. Research methods

To address the objectives set forth in this work, a combination of theoretical and general scientific methods were employed. The analysis of psychological and pedagogical resources on the research problem was conducted to understand the state of development of using immersive technology in the study of mathematical logics in secondary schools, identify research areas, and establish principles and approaches to the use of immersive technology in teaching. A summary of national and international experience in the use of immersive technology in secondary schools was performed to identify development tendencies, clarify the basic conceptual and terminological framework, and establish the conceptual foundations of the study. Theoretical analysis and systematic analysis were also utilised.

To solve the set tasks, empirical research methods were employed, including an experimental study of the use of immersive technologies in the study of mathematical logics in secondary school, expert evaluation of survey results, and observation of initial activities with the use of immersive technologies in educational activities.

3. Literature review

The problem of immersive technologies in education has been addressed by researchers such as Babkin et al. [10], Burov and Pinchuk [11], Klochko and Fedorets [12], Kovalchuk et al. [13], Mintii [14], Mintii and Soloviev [15], Mintii et al. [16], Papadakis et al. [17], Palamar et al. [18], Semerikov and Striuk [19], Semerikov et al. [20, 21, 22, 23], Shepiliev et al. [24]. The concept of immersive technologies is interpreted differently; for example, Sokolyuk [25] defines it as a complex of people's sensations located in an artificially created three-dimensional world, in which they can change their viewpoint, zoom in and out of objects, and so on.

According to Sergeev [26], the exposure of the subject to the learning environment, particularly the immersive environment, and orientation within it allows for the examination of the processes of including the subject in the "worlds" of learning, which can live according to their own laws and not necessarily correspond to the worlds of physical reality. The researcher specifies three types of exposure: exposure to the subjective world, exposure to the physical environment, and exposure to the virtual environment.

Among the investigators of the problem of edutainment, which is learning through play, in modern pedagogy, we can see scholars such as Buckingham [27], DeVary [28], Kazanci and Okan [29], Korniienko et al. [30], Riabko et al. [31], Tokarieva et al. [32], Varina et al. [33]. Addis [34], a professor at Bocconi University in Italy, points out that edutainment is a specific activity that is based on learning and satisfaction with one's own curiosity.

Semerikov et al. [35] analyse the approaches to the definition of "immersiveness", "immersive educational environment", "immersive approach in education", and "immersive educational resources"

(IER), which were used to identify the relationship between the virtual environment and the learning environment being implemented. The pedagogical aspects of learning in immersive environments are examined.

Video games for education form an essential segment of educational content today, with Digital Game-Based Learning (DGBL) becoming increasingly popular. A study by Tokac et al. [36] presents the effectiveness of video game-based mathematics training, claiming that video games contribute to the improvement of mathematical knowledge compared to traditional methods. Wouters et al. [37] have studied the influence of "serious games" on learning in detail, proving that those who learn through serious games have learned more compared to those who learned through conventional teaching methods. Scientists have different opinions on the use of games in teaching, with some stating that for the success of DGBL, it is necessary to have "correct" games for teaching, while others believe that teachers should take an active role in developing educational activities with the help of digital games [38, 39]. Teachers should adapt digital games as part of their teaching tools.

In the study by Chen et al. [40], the effect of competition in DGBL was analysed. According to the data obtained during the research, competition in DGBL was effective for mathematics, science, and language and was effective for students in schools and colleges. The highest effect was observed during task performance in puzzle games, strategy games, role-playing games, and modelling, but not in action games. As a result, it was discovered that competition in DGBL was equally effective for cognitive and non-cognitive results.

Similar results on the use of games in K-12 mathematics education were acquired by Byun and Joung [41]. This paper examines the current trend of DGBL by analysing research on DGBL for mathematics learning and achievements in mathematics learning. The authors also note future directions of DGBL research in the context of mathematics teaching. Out of 296 studies analysed, only 33 were identified as empirical and were systematically analysed to investigate current trends. Due to a lack of statistical data, only 17 out of the 33 selected studies were analysed to calculate the overall effect of digital games on mathematics education.

A related study was conducted by Clark et al. [42], who analysed the published results of research on the overall effect of digital games on learning outcomes from 2000 to 2012. Out of 1,040 papers considered, only 69 had information about the unique empirical research use of digital electronic games in education, involving a total of 6,869 respondents. The researchers concluded that games as a medium certainly provide new and powerful opportunities, but it is the active creative activity in the game environment that determines the effectiveness of the learning environment.

Gunter et al. [43] analysed the RETAIN model (Relevance, Transfer, Adaptation, Immersion, Naturalisation), which is based on the following positions: relevance represents the correspondence of the materials to the students' needs; concordance represents the necessity of presenting the academic content in accordance with the game plot; integration is based on the existing experience of students in other spheres, as well as the possibility of using the knowledge in real life; adaptation refers to a change of behaviour as a result of integration from the virtual into the real world; engagement represents intellectual involvement in the game process; and implementation of the skills acquired in the game and their use in real life.

Apart from the above-mentioned issues, the relationship between game, pedagogical, and realistic components in serious games is no less important. Harteveld [44] states that the attributes of serious games are pedagogy, low resource intensity, timeliness, harmony, experience, unambiguity, research, game elements, attributes, interactivity, involvement, learning goal, goal groups, organisation, reality, and challenge. Pedagogy declares the necessity of reflection, but the game, ideally, encourages it. The highest results are achieved by learning by doing, which means that students must not just read the text but live the learning process internally. The low level of informational intensity of resources allows children to form the ability to make self-evaluations and decisions.

An important issue is also the efficiency of DGBL. There is a variety of methods for evaluating DGBL, which leads to controversy in determining the reliability and validity of certain methods. All et al. [45] investigated various methods of assessing teaching effectiveness, which were developed by experts in the field of psychology and pedagogy through structured meetings to identify the most

important methods for conducting DGBL effectiveness studies. The suggested improvements in the methodology of determining the level of efficacy relate to the implementation of the intervention in both the experimental and control groups. The participants of the experiment themselves determine which elements should be omitted during the exercise (e.g., the instructor's supervision, additional elements consisting of essential information) and which elements will be important (e.g., procedural support, training). The investigators determined the parameters for which the similarity between the experimental and control conditions (e.g., time of influence on the workout, instructor, day of the day) can be achieved. Regarding the testing of methods, the suggested improvements concern the exposition of participants to the conditions (e.g., parameters to be taken into account when using blocked randomised design), the general design (e.g., the need for an initial test and a control group), test development (e.g., developing and running parallel tests), and testing (e.g., next steps after at least 2 weeks of training).

Gamification is the use of certain elements of games in non-gaming practices. Salen and Zimmerman [46] define a game as a system in which players are involved in an artificial conflict, defined by rules and expressed in a quantitative result. Gamification is distinguished from other game formats by the fact that its participants are focused on the purpose of their real activity, not on the game as such. Game elements are integrated into real situations to motivate specific forms of behaviour under given conditions.

4. Research results

Recent research shows that the market value of educational software in 2018 was $2.3 billion, and by 2025, this number is expected to double. This assumption indicates the active implementation and use of software in all spheres of education and culture, including immersive technologies, i.e., technologies of full or partial inclusion in the virtual world, as well as different kinds of virtual and mixed reality. However, it is first necessary to find out what kinds of technologies allow for the creation of modern content and the differences between them.

- Real Reality (RR) – the objective reality in which we exist and perceive through our senses.
- Augmented Reality (AR) – a visualisation technology associated with the combination of real-world objects and information, combined through the use of computers, capable of projecting digital information behind device screens and connecting virtual objects to the real environment. PokemonGO, which has been popular for a few years, is a great example of AR technology.
- Virtual Reality (VR) – a technology that transports people into an artificial world where the natural environment is completely altered. In general, virtual reality means the creation of an imitation of real-world experience, which people can enter at any time with the help of technology.
- Mixed Reality (MR) – the latest development in virtual reality technology, which can cause a variety of sensations. Mixed reality occurs not only in the physical or virtual world but is a mixture of the reality of our world and virtual reality, which can be seen as a supplement to reality and a supplement to virtual reality.
- 360-photos, video – content consisting of one 360° or several stitched photos and videos. This is the process of creating photos of a certain object, which are taken from different sides and combined into one package. Viewing 360-photo gives you the opportunity to see many more details, so to say, to feel them at the physical level.

The use of immersive technologies opens up numerous new possibilities in teaching and education, which are quite complicated, time-consuming or costly for traditional approaches. They outline nine facts in favour of immersive technologies, such as clearness, concentration, maximum involvement, safety and effectiveness. With the help of AR and VR, learning a subject is a much more effective way than standard teaching. The majority of publications on this problem indicate the possibility of using VR and AR technologies in the educational sphere for the purpose of visual modelling of educational

material, supplementing it with more knowledge, developing children's spatial ideas, skills of research and experimentation, extensive projecting, which saves time on learning information, accelerates learning and makes this process fun and active.

It is known that various natural and social sciences, which usually act simultaneously as consumers and providers of scientific and practical results for the field under consideration – physics, mathematics, linguistics, biology, psychology, etc. – belong to the number of calculating sciences. An important place among computational sciences is occupied by the relevant part of mathematics, which has various names: theoretical informatics, mathematical theory of calculations, cybernetics, etc.

The part of mathematics, which is a numbering science, is also not homogeneous. It includes branches of mathematical physics, the theory of numerical methods of differential equations, the theory of mass maintenance, which is used for creating operational systems, in the theory of games and so on. However, the central place in this field of mathematics, which is connected to the computational sciences, belongs to mathematical logics and algorithm theory. Often these two disciplines are combined under the joint name "mathematical logics", considering algorithm theory to be a part of mathematical logics in the broad sense of the word.

Since among mathematical disciplines, mathematical logics is the only discipline that studies the relationship between texts and their meaning, the mathematical description of this relationship is of primary importance when texts are transformed from a means of communication between people into a means of interaction with a computer.

Nowadays, mathematical logics is becoming more and more important; it is a theoretical basis for informatics, which middle school students study in grades 10-11, so it is very useful to develop and refine the concepts of mathematical logics at an early school age. It is necessary to introduce it to students as early as possible, using it in practice. We therefore propose to introduce mathematical logical elements in the school mathematics course. This approach can be closely connected with the program of developmental teaching, which is now being implemented in many schools.

However, many children find it difficult to learn mathematics at school, and one of the reasons is the loss of motivation for learning or the subject itself. To address this problem, elements of mathematical logic should be introduced in primary and secondary schools through educational games. In the process of games, children memorise different logical tasks, which form certain logical operations without noticing. Thus, the basis for learning the number of words, one of the sections of mathematical logics, is laid.

Game techniques have always been used in school education. Tests and examinations, passing from one class to another, final tests – all of these have elements of the game, but they are not always valid. The problem is that classical educational methods often ignore the simple but important fact that learning should bring joy and satisfaction and should be entertaining. It is known that the human brain is set up for the positive, that is, when instead of struggling with boredom there is a drive and positive emotions, information is absorbed more easily.

The main reason for play-based methods is to focus on mistakes. Teachers at school always focus on mistakes but rarely praise for correct answers or solutions. The fixation on mistakes causes students to concentrate more on grades than on knowledge. In computer games, on the other hand, faults are accepted and are the main tool for achieving success. Let's take the game Angry Birds, which at least once played all modern children. It vividly demonstrates how with each failure the player tries new variants of successful achievement of the goal – to kill the pigs. By playing, we know that there is nothing wrong with failure – the sooner we do something wrong, the sooner we can find a good solution. Game is one of the ways of motivation, the development of logical thinking, but not a universal peremptory mean. Gamification without high-quality educational content will not work.

In order for the learning process to be called gamifiable, it must contain the 4 characteristics that McGonigal [47] revealed in her TED talk:

- clearly defined goals that provide motivation to participate in the game;
- logical and step-by-step rules that set the limits and framework for achieving the goals;

- a stable communication system ensuring that the objectives can be achieved and the players comply with the rules;
- a voluntary agreement to participate in the game and follow the rules for achieving the goal.

Werbach and Hunter [48] emphasise the motivational function of gamification. They believe that gamification allows for the activation of people's learning activity. Moreover, gamification allows not only the creation of new games but also the use of their components for motivation. According to them, any game component can be used behind the game format to shape people's attitudes toward a certain environment.

Among the many applications of digital learning, Lifeliqe's main product, the Digital Science Curriculum, deserves special attention. This project (https://www.lifeliqe.com/products/lifeliqe-app) focuses on the K-12 science curriculum, involving students in an open-ended interaction with STEM subjects. This interaction is enabled by interactive 3D models, more than 1,500 available in AR/VR, and a large number of animated videos. Thanks to this, users can use more than 1,000 prepared and ready-to-use activities with great efficiency. An important factor of handy use is that the available digital content is fully compatible with the main natural science textbooks used in the U.S. educational system.

One of the games that has become very popular among children and teachers is Minecraft (https://minecraft.net). Minecraft is a virtual community where players can wander and interact with the world from blocks. Since its release in 2011, the game has become a cultural phenomenon. Over 200 million units were sold worldwide (data as of August 2020) [49]. Due to this success, a special version of Minecraft: Education Edition (Minecraft EDU, https://education.minecraft.net/) was released.

The Minecraft EDU educational game process is structured as follows: the teacher controls the virtual map where students play; the teacher can integrate lessons and assignments into this map. To prevent teachers from doing too much extra work, the game offers a rich library of previously created "worlds" as well as a collection of previously created lessons. The Minecraft EDU learning environment provides you with a wide range of options. For example, finding the perimeter of that particular area or distinguishing dinosaur remains from other digs. The teacher gives each student access to the buildings and places on the virtual map, thus coordinating his or her activities. This makes it possible to teach many people at the same time individually [50].

Due to its flexibility, the game is easily adaptable to different educational subjects. For those who have decided to try Minecraft EDU in their classes, you may want to consider these suggestions:

1. Before the game, discuss together with students the rules of behaviour in the virtual world. No one will be pleased if a classmate destroys a copy of the Arc de Triomphe you've been working on for a couple of sessions.
2. Confirm that your world is set up for the task of the lesson, before the start of his students. For those teachers who are too busy, Minecraft EDU offers a ready-to-use starter kit of core school subjects (https://education.minecraft.net/class-resources/lessons/).
3. Make a paper copy of the instructions, assignments, questions, or suggestions for your students. This will help them concentrate on the task.
4. Allow time for an introductory lesson to show children the basics of the game: click on the menu, perform the main actions. It is better to combine beginners players with experienced, to facilitate learning. It's important to remember that this is just a game that helps us accomplish a certain task. Combine the secondary educational environment – books, textbooks with the Minecraft environment.
5. Take a break every 30 minutes. At this time, ask students to share their accomplishments or difficulties, as well as their feelings with the class.

Let's look at a few already existing Minecraft EDU worlds that can be used by teachers of various school subjects. The first world is called Tutorial-world and is a guide to the Minecraft world. In fact, it is necessary for those teachers and students who are not familiar with Minecraft, or for those who need to update their memory about the basics of the game and the means of controlling their actions, for

example, in the creation of objects. To use this guide you only need to download the file .mcworld and import it into Minecraft: Education Edition. During the course of the course you will be accompanied by two guides – Jessica and Stephen. However, you should not forget that to get the best results, you should get the maximum amount of information, which you can get from the special knowledge base.

Fantastic-mr-fox's world is Mr. Fox's fantastic world, which gave us the idea of creating a fantastic world of our own. The use of this world in the teaching process has the following goals: to learn to recognise the meanings of individual words and whole phrases; to learn how to describe characters and events and to write stories based on the text, using the details found in the text itself. As one of the variants for the development of the teaching process itself, you can use the previous viewing of the final of the animated film "Fantastic Mr. Fox" with the subsequent analysis of the events and attempts to invent a continuation of the story. That is, students are encouraged to invent their own history of how the stars will live in the future, what kind of resources they will need, what kind of housing and its modifications they will need. "Practical" activity with the world of Minecraft Fantastic Mr. Fox is in the creation of housing for the own character in the underground zone of the virtual construction. In addition, the students are encouraged to use these coordinates, create tunnels to three farms. A separate task is to write an article for the newspaper or a story about a day in the life of the inhabitants of the underground city.

The geography teacher will enjoy worlds with such biomes as the savannah, mountains, taiga, and the ocean, for example, the world of secret-reef. This world is dedicated to learning about coral reefs, their possible structure, the most varied forms, sizes and colours. A coral reef is composed of several assemblages of coral blocks. Each of these assemblages has a certain type. For example, dead corals. Moreover, these assemblages can be realised with different forms. But there is no rule that necessarily some structure must be composed of one type of corals. More often for everything on one reef there are several types of corals. Depending on the edition, there may be different types of assemblages.

The world of project-storytelling offers its own variant of teaching, which will be useful for teachers of literature and Ukrainian language. Its purpose is to encourage the development of creative skills in writing texts. In this world, where the "Tree of Souls" is located, you will find yourself in a rural area with stores and houses. The temples of the 4 elements (Fire, Water, Air and Earth), 11 theme factories and buildings, 35 vacant lots for students to create their own buildings or businesses, 6 mini islands with unique possessions – so many opportunities encourage each of the students to create their own story.

For biology teachers there is a lesson on elephant life and protection called watr-humans-and-elephants. Interesting lesson lesson-hub-volume-i, where the author wrote that in this world there is a collection of educational activities you can engage in learning fractions or study the history of the United States in the mid-20th century. Physics teachers will find it interesting to study the properties of Redstone in the redstone-breakout and redstone-lodge worlds. In this educational virtual world you can create traps, automated crop farms, and much more. World-of-chemistry and lessons in chemistry-lessons will be of use to chemistry teachers. In these worlds there is a great table of chemistry elements of Mendeleev. Children are happy to learn the process of creation of air balloons. Teachers of informatics are interested in the program lessons/code-builder-for-minecraft-education-edition. In this course, it is necessary to use Code connection and be able to work with Scratch, CodeMake, Tynker, which also deals with 3D modelling and allows you to move the created objects in the Minecraft world.

The most interesting thing in Minecraft is the Redstone resource, which can be used to create logical schemes. Thus, the player can make their buildings interactive. The chains created with Redstone transmit energy from one unit to another, like electric chains, and the torch is needed to supply energy to the chain. If you install pins, buttons and other control elements and use them, the grader will be able to switch the lance from one position to another.

Minecraft allows players to create logical valves that perform simple logical operations. For example, by using two shafts, you can create an "AND" valve that lets "energy" through only when both levers are active, or an "OR" valve that lets "energy" through if either of the two levers are active. This system has a device of real electronics and Boolean logic, which allows to create complex mechanisms. Thanks to this feature the game can serve as a virtual constructor for programmers and engineers. The teacher

can use not only ready-made lessons, but also create their own.

One of the most widespread and popular types of games are constructors, because they allow you to learn through the gameplay and discover the basics of technical skills. A variety of programs and web resources that allow you to look at the process of creating new devices or appliances are also the essence of the designers, if you look at them for the impact on the development of skills. The online resource Tinkercad (https://www.tinkercad.com) is a web tool that allows you to model objects of any complexity, which in the future can be built on a 3D printer. Tinkercad does not have any restrictions in the professional context. In particular, it is possible to create electronic circuits and connect them to the Arduino virtual circuit board simulator. These powerful tools make it much easier to learn how to design and program new circuits for those who are just starting to use Arduino.

We investigated two virtual learning environments, one created with Minecraft EDU and the other created with Tinkercad and their practical use on the topic "Logical operators".

According to the curriculum, the subject "Logic operators" is studied during the study of the subject "Informatics" (8th grade) and is related to such issues as the basics of algorithmisation and programming, processing and storage of information. For a better understanding of the educational material is needed not only sources of information, but also working digital models. To implement these models on the basis of real mechanics or electromagnetic devices is quite difficult and ineffective, because the students, for the most part, will not be able to understand the existing analogues. In this case, it is better to use the virtual learning environment for everything, which is in fact a virtual world where most of today's children feel "at home".

Despite the large number of researches on gamification, this educational trend has not become popular in the Ukrainian education system, as evidenced by the survey conducted as part of the MoPED [51]. Only 7.5% of lecturers, 18.6% of students, and 15% of teachers considered gamification as one of the three most important educational trends. The reasons for this result lie in the weak technical base of universities, partial awareness of the teaching staff in the information and communication sphere, the use of English language in most Internet platforms, the lack of methodological methods of using gamification, the lack of financial resources for paid subscriptions.

Partly this problem can be solved by training prospective teachers to use gamification technology in the educational process of the school within the framework of university educational programs. Training of future teachers for the use of serious games must be a process that is purposeful, planned, multilevel and multi-stage nature with the organised interaction of all participants in the educational process and aimed at mastering the knowledge and skills of using serious games in educational activities with constant monitoring of the achieved results. This makes it possible to assert the necessity to include in the vocational training of future teachers disciplines aimed at acquiring knowledge and skills in the field of gamification in the educational activities of schoolchildren.

Educational training programs for future teachers of mathematics, physics and informatics do not include educational components that form competencies for using serious games in professional activities. However, the elements of such training should be included in the educational components, taking into account the departmental spheres of professional training. The topic "Logical operators" is related to such educational components as mathematical logic, algorithm theory, discrete mathematics, programming, teaching methods, etc. The inclusion of elements of gamification in these educational components will form the basis for the further use of gamification in professional activities. For this purpose it is necessary to use every opportunity. Thus, in our opinion, such possibilities can include:

- visual materials for lectures (screenshots created in the game environment or in its background, product placement);
- practical tasks with elements of gamification (full or partial use of serious games);
- independent work performed in game environments (additional points for use in the process of playing games);
- laboratory works on teaching methods (results are aimed at creating educational content and taking into account students' desire to use games).

Special attention should be paid to the training of future teachers for the knowledge and skills of using serious digital games in teaching in the teaching discipline Methods of teaching by branches of knowledge. It is necessary not only in theory but also in practice to study the stages of organisation of educational activities on the basis of serious games, such as:

- to identify the target audience of the educational content;
- to set the instructional goal;
- to create the structure of the educational content;
- to identify the elements that can be gamified;
- to implement the selected elements through a digital game;
- to use the developed educational content;
- to perform monitoring of the educational process on the spot and at the end of the day;
- to analyse the results obtained.

During the training at the HEI, future teachers need to be prepared to use serious games based on the advantages and disadvantages of gamification. Advantages include: the ability to use distance learning (both individually and collectively); the ability to use a variety of multimedia tools and modern technology; strengthening the creative abilities of individuals, development of creative thinking, self-organisation, self-control and self-discipline; less academic pressure, increasing independence in learning and self-development; increasing interest in learning through an interesting presentation of the material, which increases the level of mastering the material. The disadvantages of gamification are: the presence of deficit of communication during the training; the possibility of the emergence of irrational judgments; increased number of hours that people spend at the computer; possible technical failures in the work; the need for special training of teachers and a certain amount of time for learning new technologies; a considerable amount of time for the development and implementation of game technologies; high financial and time costs.

During our research we carried out an survey among the students of the State Higher Educational Institution "Donbas State Pedagogical University", who are studying on the educational programs of secondary education (mathematics), secondary education (physics), secondary education (informatics) or on their combination with other educational programs. Respondents were asked the following questions:

1. How do you feel about the use of any games in the educational process? (positive/negative)
2. Are you familiar with the concept of gamification? (yes/no)
3. How do you feel about limiting the use of mobile devices in educational institutions? (supportive/not supportive)
4. How do you feel about the increasing influence of mobile devices on children's education? (positively/negatively)
5. Do you support the teaching of children at school through computer games as a necessary element of the teaching process? (I do/I do not)
6. Do you support the training of adults through computer games as a necessary element for improving qualification and acquiring new knowledge and skills? (I approve/not approve)
7. Did you have your own experience of learning through the computer game? (yes/no)
8. Do you know someone who has had some experience with learning through a computer game? (yes/no)
9. Should the teaching of methods that use gamification in the teaching process be a necessary element of pedagogical education? (yes/no)
10. Are you ready to learn how to use games during your own professional activities? (yes/no)

A total of 102 students took part in the survey. The results of their responses are presented in table 1.

The results show that most of the students are familiar with the concept of "gamification", are ready to learn by playing and to teach others. Most of the respondents are ready to learn new methods and

Table 1
Results of answers during the survey.

Question	yes / positive / support	no / negative / do not support
Q1	85	17
Q2	76	26
Q3	22	80
Q4	63	39
Q5	74	28
Q6	55	47
Q7	19	83
Q8	24	78
Q9	63	39
Q10	69	33

support new forms and means of learning and do not understand the restrictions on the use of mobile devices that can be useful in educational activities. However, the number of those who have used or interacted with them is very small, although there is a tendency for the number of students who learn through games to grow.

As it was mentioned in the theoretical part of our research, we introduced elements of gamification into the educational disciplines of teaching methods. We have been offered the laboratory tasks of working out the educational scenarios of "Logical operators" in the Minecraft EDU environment (figure 1) and creating the educational project in the Tinkercad environment (figure 2). As a result of the group project, several teaching tasks were created and tested during the students' production practice at educational institutions.



Figure 1: Example of creating a logical operator in Minecraft EDU.

The aim of the educational project in the Tinkercad environment is to demonstrate the principles of algebraic logic and the construction of tables of truth, which the students studied as part of this subject. However, this material was theoretical for them, because it did not create an idea of how it could be implemented in real life. Therefore, the main condition for the effectiveness of the lessons was to create conditions for a clear demonstration of the work of logical elements. The most optimal

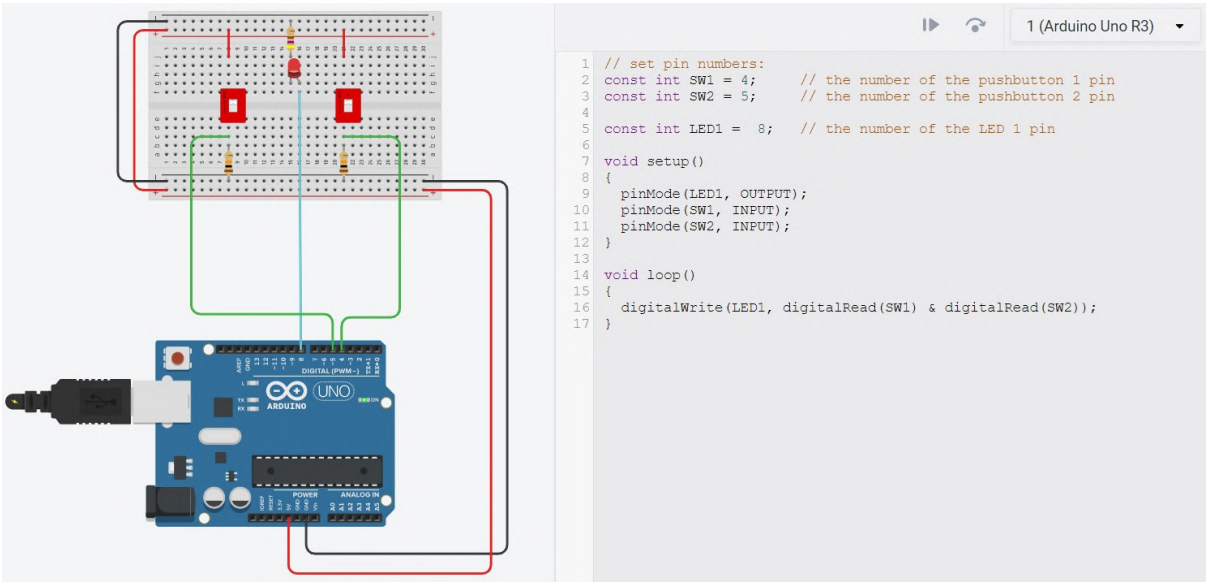


Figure 2: An example of creating a scheme for the logical operator “AND” in Tinkercad.

variant in this case is to conduct lessons with additional study of materials related to electronics and circuit engineering.

The students were given the task to independently create tables of truth for logical “AND” and “OR”, design an informational model of the circuit in the Tinkercad environment, test it on the basis of the principle circuit, and, in case of a successful result, build this circuit on the breadboard.

After the scheme was created, it should be tested and the results of the work should be compared with the results of the tables of truth. The result of this project is the creation of a physical object as a proof of the correctness of the truth tables for logical elements. This was successfully achieved due to the fact that all subject areas were taken into account in the necessary proportions with the successful implementation of the interdisciplinary approach. The goal was successfully achieved and the results of their work resulted in an electrical scheme, which fully corresponded to the results of their calculations and reflected the principles of logical “AND” and “OR” operation.

With the help of the Tinkercad environment you can introduce students to the concept of relay-contact circuits. We explain, under the contact we mean the physical body, which can exist in only two states – “on”, “off”, which we will denote as 1 and 0 accordingly. Connecting contacts in series corresponds to the operation “conjunction”, and connecting them in parallel corresponds to the operation “disjunction”. By opening contact we denote a contact that does not conduct current, which corresponds to the negation operation of the algebra of statements. In other words, we show that the algebra of relay-contact circuits, which is isomorphic to the algebra of statements, is created. The analogous equivalences of the algebra of statements correspond to equivalences of the algebra of relay-contact schemes. Using examples, it can be shown that each of the investigated schemes is described by the corresponding formula of the algebra of relay-contact schemes. Thus, the practical significance of mathematical formulas is explained.

The students’ reports on the internship and their own observations revealed a significant interest in the suggested tasks. Despite the fact that the topic “Logical Expressions. Changes of Logical Type. Logic operations” in the 8th grade belongs to the section “Programming” and is often difficult to understand, the material was studied at a high level. This is evidenced by the fact that further use of the knowledge gained during the study of the topic “Logical Expressions. Changes of Logical Type. Logic operations” in such topics as “Algorithms with branching” and “Cyclic algorithms” did not cause any difficulties in learning these new topics. Moreover, the homework assignment, which students often do without enthusiasm, was completed successfully and absolutely by all students without exception (boys and girls), indicating their interest in this educational tool. The survey of students showed that close to 18% of 8th grade students had active Minecraft accounts and participated in collaborative game sessions.

This difference did not have much effect on the results of the tasks. Children who already have Minecraft game accounts completed the tasks quicker than their peers. However, the virtual learning environment created by the Tinkercad tools has caused more interest among children who are engaged in robotics. This can be explained by the fact that robotics has a more realistic realisation than the imaginary world of Minecraft.

5. Conclusions

The development of computer technology and the general increase in digital literacy, coupled with the challenges posed by the COVID-19 pandemic, have necessitated the search for new, more effective ways and methods of learning. In addition to the use of electronic educational resources in the form of websites, blogs, and channels, there is a growing need to implement learning through technologies that provide a high level of visualisation combined with "interaction" with the physical environment. In other words, there is a pressing requirement for teaching using immersive technology that integrates the virtual environment with the physical environment, allowing users to naturally interact with mixed reality, which includes augmented (AR) and virtual (VR) realities.

The practical application of immersive technologies in the educational process is most effectively combined with gamification – the use of certain game elements in non-game practices. Game elements are integrated into real situations to motivate specific forms of behaviour under given conditions. The positive results of this synergy can be observed through examples such as Lifeliqe's Digital Science Curriculum, the special version of Minecraft: Education Edition, and the online resource Tinkercad, a web tool that enables the modelling of objects that can be built using a 3D printer.

During the practical part of the research, it was found that most students are familiar with the concept of "gamification" and are ready to learn and use this methodology in their educational activities. Furthermore, studying the topic "Logic Operators" in the Minecraft EDU environment and creating a teaching project in the Tinkercad environment showed a growing interest in mathematical logics and improved quality of work results among both students and educators.

Therefore, we can conclude that gamification of the educational process, a relatively new form for Ukraine, is a promising tool to enhance the quality of education for children, adolescents, and adults, deepening the level of acquired knowledge and enabling more effective use of skills and abilities. However, its successful implementation in the education system requires the establishment of a clear procedure and adherence to the key stages of creating a game mechanism. Reviewing methods of using digital game content, creating a library of digital electronic educational resources, and developing methods for teaching the use of gamification for further application are new topics for further scientific research and development.

Declaration on Generative AI: The authors have not employed any Generative AI tools.

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Collaborative learning in the system of training future information technologies specialists as an educational strategy for the fundamentalization of the sustainable development of education

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Abstract

The article, based on empirical and theoretical research, reveals the place of collaborative learning in the system of training future information technology specialists in the context of the implementation of sustainable development goals. The authors of the article distinguish between the concepts of cooperative and collaborative learning, understanding the latter as a more psychologized, intellectualized learning, based on the disclosure of the synergistic effects of group work. In the work proposed a methodology for using collaborative learning in the system of training future information technology specialists to participate in team sports programming as one of the subtypes of subject competitions. The article presents a scheme of the iterative process of forming a sports programming team. It involves determining the primary team composition, defining roles, training, evaluating team success, changing team composition and redistributing roles. Considering the stages of training in the context of collaborative learning, it is proposed to use the following methods: pair programming, joint code development, code review, retrospective, code sessions. A survey was conducted of university lecturers involved in the training of future IT specialists. The results of the survey were processed using methods of system analysis, Natural Language Processing (NLP), statistical methods (Wilcoxon signed-rank test), computer modeling, and data visualization. It was found the common and different key characteristics of cooperative and collaborative learning in the opinion of computer science lecturers. The analysis of the results of the respondents' answers indicates that the respondents more often use cooperative learning compared to collaborative learning in the process of forming students' teamwork skills. At the same time, those university lecturers who constantly use collaborative learning in their activities note its positive impact on the formation of students' teamwork skills, the effectiveness of learning activities, which is manifested in solving tasks (simple and complex) and their better understanding, the formation of effective goal setting, effective emotional interaction and common values of group activities.

Keywords

collaborative learning, cooperative learning, teamwork skills, information technology education, sports programming, sustainable development goals, pair programming, code review, natural language processing (NLP), system analysis, computer modeling, data visualization, team formation, educational methodology, psychologized learning

CEUR-WS.org/Vol-3918/paper131.pdf

AREdu 2024: 7th International Workshop on Augmented Reality in Education, May 14, 2024, Kryvyi Rih, Ukraine
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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

1. Introduction

Sustainable development in education is aimed at creating systems, strategies, and approaches that promote the development of education in harmony with the current needs of society, while ensuring that opportunities for future generations are preserved [1]. Sustainable development in education is aimed at creating a system in which future professionals gain knowledge and skills necessary for the development of a sustainable and responsible community, capable of acting in compliance with ecological standards, in collaboration, in harmony with the world, ensuring its well-being in the long term [2, 3, 4, 5]. One of these skills is communication skills, social interaction skills, the ability to collaborate and solve problems collectively [2, 3, 4, 5].

One of the approaches in which students work together in groups or teams to solve tasks and problems is collaborative learning [6, 7]. Collaborative learning can contribute to the sustainable development of education, because it promotes the development of critical thinking, tolerance and the ability to work together on global problems [6, 7]. In collaborative learning students can better understand the importance of sustainable development. This is achieved by working together on specific tasks or projects, including IT projects in the field of ecology, economics, society, etc. Therefore, collaborative learning can contribute to the training of professionals who understand the importance of sustainable development and have the skills to collaborate to achieve the goal.

One of the consequences of the mass informatization of society and the active use of information technologies in professional activities, education and leisure is the transformation processes in education [8]. They are also related to the requirements for training school and university graduates. At the same time, the system of graduates' professional qualities must meet the requirements of the modern digital society – a high level of information culture, the formation of key and professional competencies, the ability to self-learn, the ability to solve non-standard problems and adapt to changes in the environment [9].

Besides, a modern specialist must possess mental properties, professional skills and abilities that would help him or her to solve non-standard and atypical tasks, flexibly adapt to unexpected situations, rationally, creatively, independently solve a wide range of life and professional problems that may arise, generate new ideas, and be fluent in the latest technologies.

In the information society, the process of training information technology specialists is very important, because they take an active part in ensuring the smooth functioning of any information system, determining the level of development and penetration of information technology in all spheres of life, economy, and industry.

The global pandemic was one of the factors that influenced the quality of professional training of students in information technology [10, 11]. It led to the transition to distance or blended learning, raised many questions about the methodology of organizing educational activities and the selection of appropriate teaching methods and technologies [12, 13, 14]. It is very important to ensure the conditions for teamwork when training students in information technology, especially in the field of programming [15]. Therefore, teachers of higher education institutions were forced to find a new teaching technology and adapt to the conditions of distance learning, in particular, to actively use group methods of working with students based on collaborative learning.

In the process of training modern information technology specialists, the issue of development of their teamwork skills through collaborative learning is very important. Among the scientific works devoted to the formation of teamwork skills in future information technology specialists, two areas of research can be distinguished: the first is researches devoted to the use of collaborative learning in the process of professional training of students in computer science, the second is the use of distance and blended learning technologies for the formation of teamwork skills.

Berglund [16] describes the process of formation of engineering students' skills to work in multi-disciplinary teams and solve social issues in distance learning. Tudevdagva et al. [17] describes the implementation of active learning methods (eduScrum, JigSaw, problem based learning, practical and team-based learning) in engineering courses. Sarrade and Lermigeaux-Sarrade [18] considered he process of integrating sustainability and ethics into team-based and project-based learning with computer

science students.

Dowdall et al. [19] pay attention to the development of communication and other soft skills among computer science students. The main focus in the training of future specialists in computer science is on the formation of professional competences, and the development of communication skills of future specialists remains in the shadows. The research has shown that the use of team projects based on a multinational, intercultural, multidisciplinary and intensive methodological approach contributes to the formation of interaction skills and effective teamwork in computer science students.

Matthíasdóttir and Loftsson [20] share their experience of implementing flipped classroom technology and team learning in the process of teaching programming computer science students. Based on experimental training and a survey, the authors conclude that students were interested in the flipped classroom technology, provided that there was a well-prepared distance course.

Xu et al. [21] consider pair programming, as a mode of collaborative problem solving in computer programming education (asks two students work in a pair to co-construct knowledge and solve problems). The research results suggest four models of cooperation in pair programming: a consensus-achieved pattern, an argumentation-driven pattern, an individual-oriented pattern, and a trial-and-error pattern.

Conte et al. [22] describes the results of an experiment on teaching parallel programming computer science students. The experiment used three different teaching methodologies: traditional, Problem Based Learning, and Team-Based Learning. The results of the research allow us to conclude that it is possible to teach parallel programming students without prior knowledge of computer science, while obtaining high scores and interest in such teaching.

Conte et al. [22] analyzes collaborative learning from different perspectives and concludes that collaborative learning can be applied to online learning, distance learning, and cross-cultural learning. The research shows that the effectiveness of collaborative learning can depend on a number of factors, such as the organizational environment of collaborative learning, the level of interdependence between group members, as well as the type of tasks performed, personal characteristics, etc.

Ramskyi et al. [23] considers the methodology of using massive open online courses in the process of training future information technology specialists. It proves the importance of attracting students to use open online courses as a means for self-education and self-development and formation of collaborative learning skills.

An important aspect of collaborative learning for information technology professionals is specific and meaningful interactions in the human-computer system [24]. In collaborative learning, this interaction can be considered as a “human-computer system small group”.

The review of scientific studies shows that they pay little attention to the description of the methodology of using collaborative learning in the training of future information technology professionals.

The purpose of the study is to find out the place and significance of collaborative learning in the structure of professional training of information technology students and the impact of its use on the development of students’ skills of interaction and effective teamwork, student training for team programming in the context of the implementation of sustainable development goals.

2. Selection of methods and diagnostics

In this research, we used a system of methods, among which the most important were: systemic, problematic, targeted, ecological (to understand the place and importance of collaborative learning as one of the ways to achieve the Sustainable Development Goals – №4 “Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all”), pedagogical, social and psychological (to reveal the phenomenology of group work which is used in the collaborative learning), cognitivistics (to understand the phenomenon of collective and individual minds), autopoiesis (to analyze the phenomenon of collaborative learning as a sociobiological and cognitive phenomenon), psychological (to analyze group dynamics and the phenomena of internal and external motivation in the process of implementing collaborative learning). The questionnaire method was used based on the developed own questionnaire.

To achieve the goals of the study, a questionnaire was developed for teachers using Google Forms. University lecturers were asked the following questions in the questionnaire that we developed:

1. Please indicate which specialties you are currently teaching (or have teached in recent years) at your higher education institution.
2. What modern educational technologies do you use in teaching students?
3. What do you understand by cooperative learning?
4. What do you understand by collaborative learning?
5. Do you use cooperative learning methods in your teaching practice? (Answer options: yes, often; yes, seldom; no.)
6. Do you use collaborative learning methods in your teaching practice? (Answer options: yes, often; yes, seldom; no.)
7. Have you involved students in team project work? If yes, in what form was the project work carried out? (Answer options: yes (auditory classes); yes (optional work); yes (students' practice); no.)
8. Do you prepare student teams for participation in team programming? (Answer options: yes; no.)
9. If you have prepared student teams for competitions, what methods or technologies did you use for training (If not, put "–")
10. When you used collaborative learning, did you observe an increase in the effectiveness of learning activities, which was manifested in solving relatively simple tasks? (Answer options: yes; I cannot decide; no; I do not use collaborative methods in teaching.)
11. When you used collaborative learning, did you observe an increase in the effectiveness of learning activities, which was manifested in solving relatively complex tasks? (Answer options: yes; I cannot decide; no; I do not use collaborative methods in teaching.)
12. Did the use of collaborative learning contribute to a better understanding of the tasks and the formation of effective goal setting? (Answer options: yes; I cannot decide; no; I do not use collaborative methods in teaching.)
13. Did the use of collaborative learning contribute to the formation of effective emotional interaction in the group? (Answer options: yes; I cannot decide; no; I do not use collaborative methods in teaching.)
14. Did the use of collaborative learning contribute to the formation of effective cognitive interaction in the group? (Answer options: yes; I cannot decide; no; I do not use collaborative methods in teaching.)
15. Did the use of collaborative learning contribute to the formation of common values in the group? (Answer options: yes; I cannot decide; no; I do not use collaborative methods in teaching.)
16. Rate on a scale from 1 to 10 the impact of cooperative learning on the development of students' teamwork skills. 1 – no impact at all, 10 – great impact.
17. Rate on a scale from 1 to 10 the impact of collaborative learning on the development of students' teamwork skills. 1 – no impact at all, 10 – great impact.

To analyze the survey results, we used system analysis methods, statistical methods (Wilcoxon signed-rank test, analysis of standard deviation and mean values), NLP methods [25], digital modeling, and data visualization. The research results were processed using Google Sheets [26], Google Collaboratory [27], and the Python programming language [28].

Natural language processing (NLP) was implemented using the Python programming language [28], the Natural Language Toolkit (NLTK) open-source library [25]. The sequence of processing respondents' answers was as follows (figure 1):

The data were statistically processed using the Wilcoxon signed-rank test [29, 30]. It was used to find out whether there is a statistically significant difference between the respective estimates of the impact of cooperative learning and collaborative learning on the development of students' teamwork skills. In this case, we consider a "Typical" shift to be a shift towards an increase in the value of the score when

Raw text —>
—> Tokenization —> Text cleaning —> POS tagging —> Remove Stop words —>
—> Lemmatization —>
—> Cleaned text —>
—> NLP Model

Figure 1: The sequence of processing the respondents' text answers.

finding a difference between the respondent's assessment of cooperative and collaborative learning, and an "Atypical" shift to be a shift towards a decrease in the value of the score. Differences between the respective respondents' assessments of the impact of collaborative learning and cooperative learning on the development of students' teamwork skills that are equal to zero are ignored when applying this test. At the same time, we formulate the following hypotheses:

H1: the intensity of "Typical" shifts is statistically significant at the level of significance $a < W$ does not exceed the intensity of "Atypical" shifts.

H2: the intensity of "Typical" shifts statistically significantly exceeds the intensity of "Atypical" shifts at the level of significance $a < W$.

The sum of the ranks of the differences in respondents' estimates characterizing the "Atypical" shift (R_{atyp}) is calculated by the formula (1).

$$R_{atyp} = \sum_{i=1}^{k} r_i, \tag{1}$$

where:

- k is the number of respondents' answers with a shift value that is not equal to 0 (the number of atypical shifts);
- r_i is the rank of differences in respondents' answers that characterize the "Atypical" shift;
- i – index, $i = 1, \ldots, k$.

We find R_{cr} in the table for the Wilcoxon signed-rank test for a given n (the number of "Typical" and "Atypical" shifts) at the significance level W, W is defined as 0.05 or 0.01, that is, $a < 0.05$ or $a < 0.01$. If $R_{atyp} >= R_{cr}$, then at the level of significance W, the intensity of "Typical" shifts is statistically significant at the level of significance $a < W$ does not exceed the intensity of "Atypical" shifts, we accept the hypothesis $H0$. If $R_{atyp} < R_{cr}$, the intensity of "Typical" shifts statistically significantly exceeds the intensity of "Atypical" shifts at the level of significance $a < W$, the hypothesis $H0$ is refuted, we accept the hypothesis $H1$.

We also used the following formulas to compare the mean values ($\bar{X}$) and standard deviations (σ) of the estimates of the impact of cooperative learning and collaborative learning on the development of students' teamwork skills. σ – the standard deviation is calculated by the following formula (2).

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{X})^2}{n}}; \tag{2}$$

where:

- n is the number of respondents' answers;
- x_i is the value of the assessment given by the i-th respondent, $i = 1, \ldots, n$;
- $\bar{X}$ – the expected value (arithmetic mean) (formula (3))

$$\bar{X} = \frac{\sum_{i=1}^{n} x_i}{n}. \tag{3}$$

3. Results and discussion

Nowadays, there is a need to train a competitive information technology specialist who is able to navigate the changing information society and is capable of self-learning. To do this, it is necessary to ensure that future specialists develop knowledge of the theoretical foundations of information technology, general competencies (ability to learn, communicate in a foreign language, work in conditions of uncertainty, plan their workload and effectively distribute work, maintain high performance, etc.) and professional competencies (the ability to quickly and easily learn new information technologies, apply new standards in the field of information systems and technologies, analyze and select the necessary data among the existing information collapse in the global network, form new competitive ideas and implement them in projects, develop business solutions, evaluate new technological proposals, etc.).

The requirements for training IT specialists are laid down in the state standard of higher education. They provide for the formation of a system of general and professional competencies in students, some of which are formed in the process of collaborative learning:

- Ability to work in a team.
- Skills of interpersonal interaction.
- Ability to act in a socially responsible and conscious way.
- Ability to apply knowledge in practical situations.
- Ability to develop and manage projects.
- Ability to develop business solutions and evaluate new technological proposals.
- Ability to participate in the design of software, including modeling (formal description) of its structure, behavior and processes of functioning.
- Ability to formulate and ensure software quality requirements in accordance with customer requirements, technical specifications and standards.
- Ability to formalize the obtained work results in the form of presentations, scientific and technical reports.
- Ability to formulate new competitive ideas and implement them in projects (startups).

Collaborative learning is defined as the joint organization of learning activities in which students with different abilities work in small groups to complete a project or solve a task.

A distinction should be made between cooperative and collaborative learning. During cooperative learning, each student in the group performs the task assigned to him or her. At the same time, cooperation requires the distribution of tasks among all members of the working group, and each is responsible for a separate part of the task in order to combine them effectively to achieve the goal. Collaboration involves the mutual involvement of group members in interaction through coordinated efforts to solve the task. The main focus is on the dynamics of cooperation within the collaborative group rather than on the individual completion of the task [31].

In collaborative learning, multifaceted subject-subject relations are created that influence the course and outcome of learning activities. Students are exposed to the idea and practice of equality, given the opportunity to acquire competence in professional interaction, learn to accept or reject the position of another participant in the training, coordinate their actions with his or her actions, develop volitional traits, assert themselves, defend and protect their own opinions and academic achievements.

The fundamental ancient Greek educational concepts of self-knowledge ("know thyself") and self-care ("take care of yourself") were developed in the interpretation of M. Foucault [32, 33]. Based on these concepts, we consider the student as a person who independently builds his or her educational trajectory, acquires knowledge, gains practical experience in their application, and realizes himself or herself as part of a team, solving common problems. The art of teamwork, leadership, creativity, and critical thinking are one of the 21st century skills needed to achieve success in the professional field and ensure sustainable development [2, 3, 4, 5, 7].

An important way to acquire collaboration skills is to prepare for subject competitions and participate in them. Here, collaboration can be implemented as interaction with a mentor and as teamwork.

Subject competitions provide an opportunity to develop students' cognitive activity and contribute to the formation of their analytical thinking. Team sports programming is one of the subtypes of subject competitions in which students of information technology can participate.

Collaborative learning tools (as opposed to traditional ones) contribute to the efficiency of the team's work. That is why it is appropriate to use collaborative learning in the process of preparing for competitions in team sports programming.

Here are some specific examples of how collaborative and cooperative learning can be used in training sports programming teams.

It often happens that in a sports programming team, each team member specializes in a certain type of task. An example of cooperative learning would be a process in which each team member works on the tasks that best suit their knowledge. That is, team member M_1 develops a solution for task T_1 on a computer, team member M_2 develops an algorithm for solving task T_2, and M3 works on task T_3. Team members work on their own parts and collaboration between them is minimal.

Below are a few examples of how cooperation described above can transformed into collaboration:

1. While team member M_1 is programming task T_1 on the computer, team members M_2 and $M3$ work together on the algorithm for task T_2.
2. Team member M_1 writes the code to solve problem T_1, while M_2 monitors this process (which can help to detect errors at an early stage). At the same time $M3$ works on the algorithm for task T_2.
3. Team member M_1 writes the code to solve problem T_1, while M_2 spends some time developing input data sets (tests) for T_1 and then M_2 monitors the coding process of M_1 (which can help to detect errors at an early stage). At the same time $M3$ works on the algorithm for task T_2.

We suggest the following stages of preparation for competitions in team sports programming:

1. Formation of the team.
2. Defining the roles and fields of specialization of each participant (for example, one team member may have the most experience in dynamic programming, while the other team member may have experience in solving problems using graph theory methods).
3. Training (acquisition, improvement, and development of knowledge in algorithmization and programming, development of creativity, critical thinking, problem solving, communication skills, negotiation skills, empathy, adaptation, initiative, presentation skills, etc.)

This process is usually not linear; at any stage of the process, there may be a need to return to the previous stage, and it may be iterative (for example, the composition of teams may change during the preparation process). This is shown in figure 2.

Let's take a more detailed look at the training stage from the perspective of collaborative learning. During training, it is advisable to use the following collaborative methods:

- pair programming is a programming methodology in which two programmers work on the same task using the same computer. One programmer writes the code, while the other analyzes it, controls the quality, and provides advice and assistance;
- collaborative code development is a program code development process in which several developers work together on the same program or project, using special tools and collaborative development technologies to help improve efficiency and quality of work;
- code review – the process of checking program code performed by another developer or development team to ensure quality, identify errors, and ensure code compliance with best practices and standards;
- retrospectives – a team (or several teams) meet once in a certain period of time (a week or two) to evaluate the work done, highlight strengths and weaknesses, and develop an action plan for the future;
- code sessions – programmers get together to solve complex problems or improve the code of already solved problems, discuss problems that arise and share knowledge.

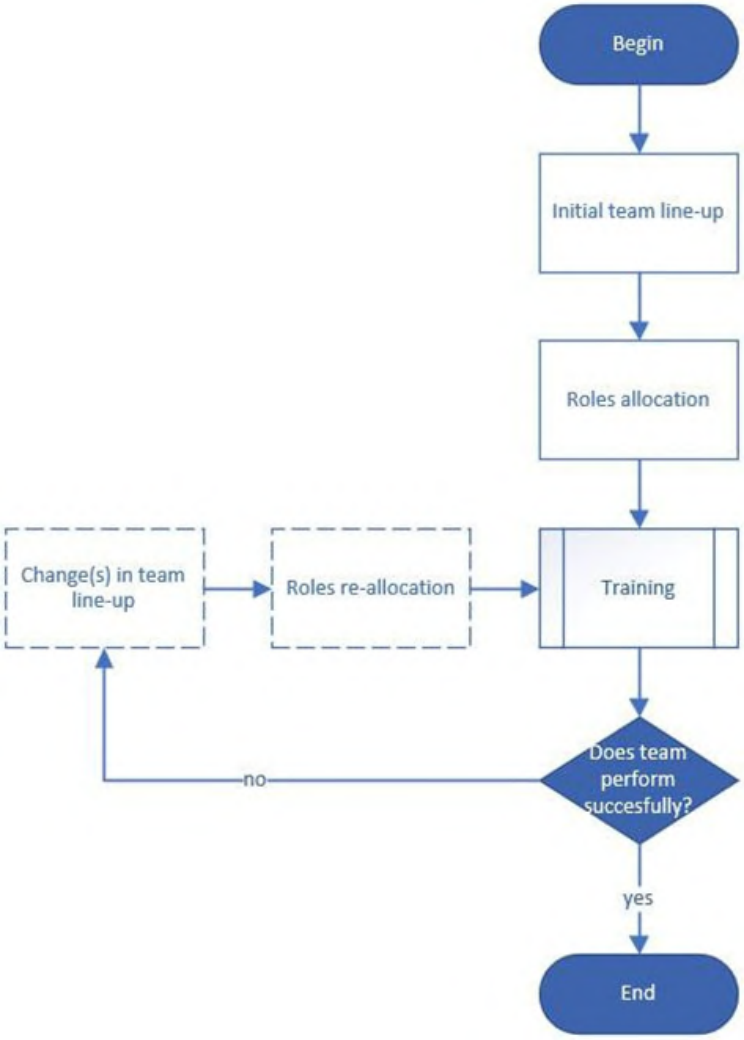


Figure 2: The iterative process of forming a sport programming team.

This allows each team member to contribute to the solving of a problem, receive feedback from other members, and improve their skills.

The team can also use online resources and platforms for collaborative programming, such as GitHub, GitLab, Bitbucket, Jira, Confluence, and others. These platforms allow the team to work on a project together, share knowledge and experience, use a version control system, assign responsibilities, create documentation and implement other useful features.

Future IT specialists must not only have the necessary knowledge, but also be ready to develop independently and easily adapt to changes. This is due to the rapid development of this industry. Let's demonstrate this on the example of developing business applications that work in browsers and are developed using the .NET web development stack. In the last 10 years alone, it has been completely updated several times (table 1).

Table 1
Backend and frontend technologies for developing business web applications using the .NET development stack.

Backend technologies	Frontend technologies
ASP.NET	HTML/CSS + JavaScript
ASP.NET MVC	RAZOR + frameworks like jQuery
ASP.NET WebAPI	TypeScript VueJS, Angular, React

As you can see from table 1, front-end and back-end developers need to update their knowledge on a regular basis. In addition, their roles and contributions to the final product are being rethought. It should also be noted that IT specialists must be a "team player", that is, they must work effectively on the overall result as a team member.

We conducted a survey of information technology lecturers using the questions presented above in the following higher education institutions: Dragomanov Ukrainian State University (Kyiv, Ukraine), Borys Grinchenko Kyiv Metropolitan University (Kyiv, Ukraine), State University of Trade and Economics (Kyiv, Ukraine), Institute of Pedagogy of the NAES of Ukraine (Kyiv, Ukraine), Higher educational institution "University of Educational Management" of the NAES of Ukraine (Kyiv, Ukraine), Vinnytsia Mykhailo Kotsiubynsky State Pedagogical University (Vinnytsia, Ukraine), Public Higher Educational Establishment "Vinnytsia Academy of Continuing Education" (Vinnytsia, Ukraine), Communal institution of higher education "Vinnytsia Humanitarian Pedagogical College" (Vinnytsia, Ukraine), Ternopil Volodymyr Hnatiuk National Pedagogical University (Ternopil, Ukraine), Drohobych Ivan Franko State Pedagogical University (Drohobych, Ukraine), Zhytomyr Ivan Franko State University (Zhytomyr, Ukraine), Pavlo Tychyna Uman State Pedagogical University (Uman, Ukraine), Taras Shevchenko National University "Chernihiv Colehium" (Chernihiv, Ukraine), Berdyansk State Pedagogical University (Berdiansk, Ukraine). 42 lecturers participated in the survey.

The results of the survey of information technology lecturers revealed that they use the most relevant teaching methods and technologies in the educational process, including project method, startup projects, flipped learning, artificial intelligence technologies, simulation technologies, gamification technologies, STEAM technologies, problem-based learning, collaborative learning, cooperative learning, blended learning technology, discussion technologies, interactive methods, case methods, and others. Among the forms of teaching, lecturers highlighted distance learning. In their teaching practice, respondents widely use online platforms and courses, learning platforms (Moodle, Collaborator, and Google Classroom), simulation platform, interactive e-books and resources, video conferences (using Zoom, Google Meet, and Tims), mobile applications for learning, digital educational games, artificial intelligence platforms, and others.

The analysis of the lecturers' answers to the questions "What do you understand by cooperative education?" and "What do you understand by collaborative learning?" was conducted to find out the contextuality of the concepts of cooperative and collaborative learning, which concepts are key for the respondents in defining cooperative and collaborative learning.

The frequency analysis of keywords in the respondents' description of the concepts of cooperative and collaborative learning was based on Natural Language Processing (NLP) technologies. The analysis was conducted using the Python programming language on the Google Colaboratory platform. We performed preprocessing of the data (tokenization, text cleaning, part-of-speech tagging (POS tagging), removing stop words, lemmatization), calculated statistics of word frequency distributions, and built a digital graphical model. Based on the results of processing the respondents' answers using NLP technologies, the following results were obtained.

As a result of the analysis of teachers' answers to the question "What do you understand by cooperative learning?" based on the frequency distribution of keywords (figure 3, figure 5 (a)), it was found that the key characteristics of the content of the concept of cooperative education for respondents are 'teaching' 'based' on 'cooperative' 'work' in a 'small' 'group' (learning based on cooperative work in a small group), 'learning' 'together' to 'achieve' a 'common' 'goal'.

The frequency analysis of lecturers' answers to the question "What do you understand by collaborative learning?" based on the distribution of keywords (figure 4, figure 5(b)) showed that the key characteristics of the content of the concept of collaborative learning for respondents are 'learning' 'work' of students in a 'small' 'group' 'based' on 'collaborative', who have different 'abilities' and cooperate 'together' to 'solve' problems or 'complete' 'project' 'task'.

So, the common key characteristics of cooperative and collaborative learning are 'teaching' or 'learning' 'work' of students in a 'small' 'group', 'learning' 'together'. The difference in the respondents' answers is that cooperative learning is supposed to 'achieve' a 'common' 'goal', while in the characterization of collaborative learning the goal is specified and indicates 'solve' problems or 'complete' a

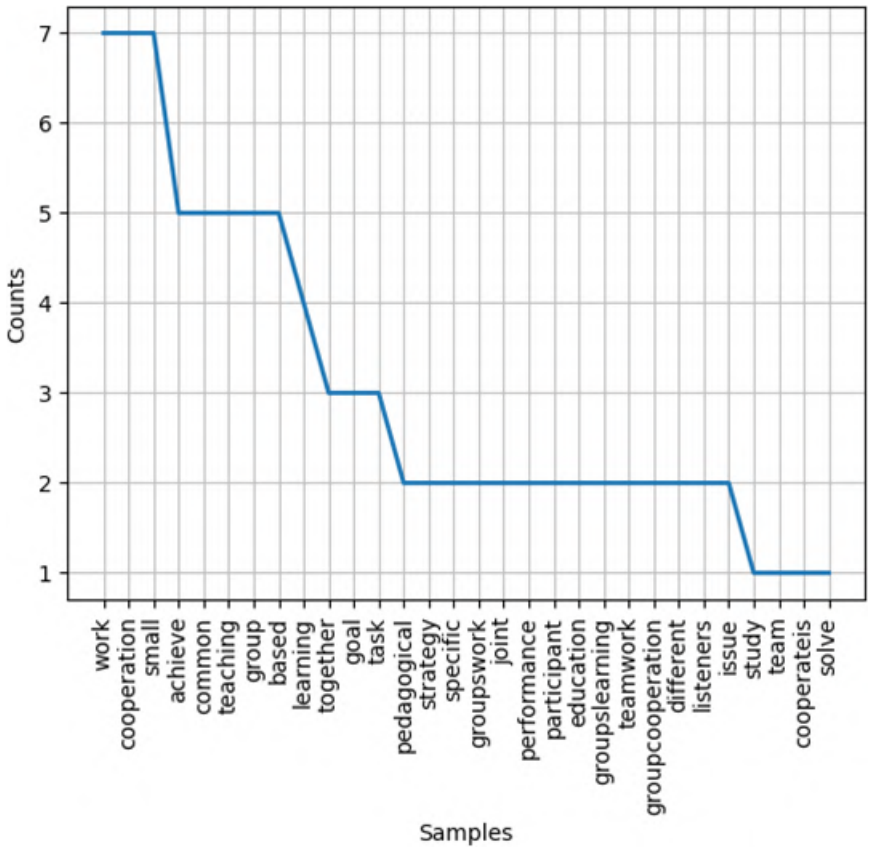


Figure 3: Frequency distribution chart of keywords characterizing the concept of cooperative learning.

'project' 'task'. The main difference in the characteristics of cooperative and collaborative learning is that cooperative learning involves cooperative work and collaborative work respectively.

Let's find out if there is a statistically significant difference in the respondents' assessment of the impact of cooperative and collaborative learning on the development of students' teamwork skills. For this purpose, we will use the Wilcoxon signed-rank test. We will form a table of the values of the respective ratings of the respondents, the difference between which is not equal to zero, and the ranks of the absolute values of the differences (table 2).

We calculate the sum of the ranks of the differences in respondents' ratings that characterize the "Atypical" shift (R_{atyp}, formula (1)):

$$R_{atyp} = \sum_{i=1}^{8} r_i = 102.$$

The critical values of R_{cr} for the Wilcoxon signed-rank test for $n = 23$ according to the table of critical values for this test are equal:

- for $a < 0.05$ the $R_{cr} = 83$,
- for $a < 0.01$ the $R_{cr} = 62$.

Since R_{atyp} = 102 is greater than $R_{cr} = 83$ ($102 > 83$) at $a < 0.05$, and even more so than $R_{cr} = 62$ at $a < 0.01$ ($102 > 62$), we accept the hypothesis $H0$. This means that the intensity of the "Typical" shifts is statistically significant at the level of significance $a < W$ does not exceed the intensity of the "Atypical" shifts, that is, the value of respondents' assessments of the impact of cooperative learning on the formation of students' teamwork skills is statistically significant at the level of significance $a < 0,05$, (especially at the level of significance $a < 0.01$) do not differ significantly from the values

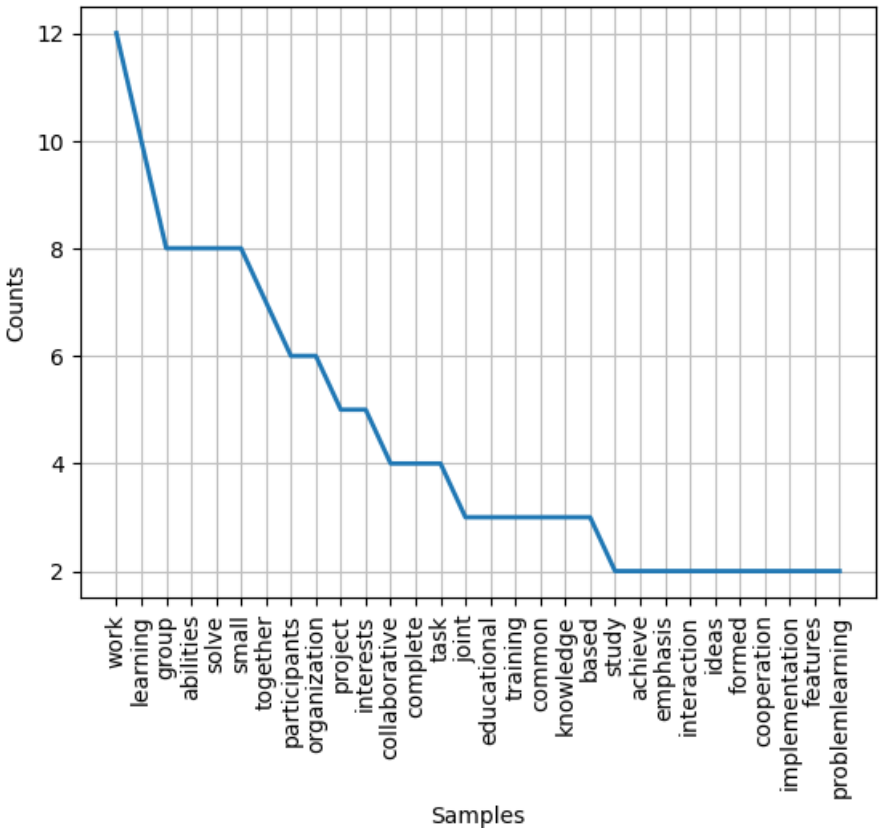


Figure 4: Frequency distribution chart of keywords characterizing the concept of collaborative learning.



(a) (b)

Figure 5: Word cloud of keywords characterizing the concept of cooperative learning (a) and collaborative learning (b).

of respondents' assessments of the impact of collaborative learning on the development of students' teamwork skills.

There are no significant differences between the respondents' assessments of the impact of cooperative and collaborative learning on the development of students' teamwork skills. Compare the mean values (σ) and standard deviations (σ) of the estimates of the impact of cooperative and collaborative learning on the development of students' teamwork skills (table 3).

As can be seen from table 3, the mean values of the impact assessments of cooperative and collaborative learning do not differ significantly. However, based on the values of standard deviations, we can say that the scores of collaborative learning on average fluctuate less relative to the mean than the scores of cooperative learning. That is, they are more homogeneous.

The slight differences between the respondents' assessments of the impact of collaborative and cooperative learning on the development of students' teamwork skills can be explained by the fact that they have much in common. Both collaborative and cooperative learning are implemented by organizing

Table 2
The value of respondents' evaluations of the impact of cooperative and collaborative learning on the formation of teamwork skills among students, the difference between which is not equal to zero, and the ranks of the absolute values of the differences.

Order numbers of the shifts, m	Evaluations of the impact of cooperative learning, a_i	Evaluations of the impact of collaborative learning, b_i	Difference, $b_i - a_i$	The absolute value of the difference, $\|b_i - a_i\|$	Ranks of absolute values of differences, r_i
1	1	7	6	6	23
2	9	10	1	1	4.5
3	9	6	-3	3	19
4	8	10	2	2	12
5	8	9	1	1	4.5
6	5	8	3	3	19
7	5	7	2	2	12
8	7	5	-2	2	12
9	8	9	1	1	4.5
10	9	7	-2	2	12
11	2	5	3	3	19
12	7	8	1	1	4.5
13	8	5	-3	3	19
14	10	9	-1	1	4.5
15	10	7	-3	3	19
16	7	5	-2	2	12
17	7	9	2	2	12
18	7	8	1	1	4,5
19	8	9	1	1	4,5
20	5	8	3	3	19
21	4	6	2	2	12
22	7	6	-1	-1	4.5
23	7	10	3	3	19

Table 3
Arithmetic means ($\bar{X}$) and standard deviations (σ) of the estimates of the impact of cooperative and collaborative learning on the development of students' teamwork skills.

Teaching method	Expected value (arithmetic mean), $\bar{X}$	standard deviation, σ
cooperative	7.21	1.95
collaborative	7.57	1.55

a small group that has its own typical patterns of existence and development – group dynamics.

Regarding the use of cooperative and collaborative teaching methods by respondents in educational practice, the following data were found (figure 6).

The distribution shown in this graph indicates the dominance of cooperative learning compared to collaborative learning. We explain this distribution by the fact that cooperative learning is more traditional and established, and therefore is used more often. Collaborative learning is relatively new, innovative and aimed at unlocking the potential of the individual in the process of joint activities.

The results of respondents' answers for the question "Have you involved students in team project work?" are shown on figure 7. The distribution shown in this graph indicates the dominance of auditory classes in lecturers' educational practices. Auditory classes are almost 4 times more prevalent than the optional work. We believe that this distribution is a manifestation of an established tradition in which collective learning dominates both in actual and contextual formats. Collective learning needs more external control and management by the lecturer, in which external motivation is significant,

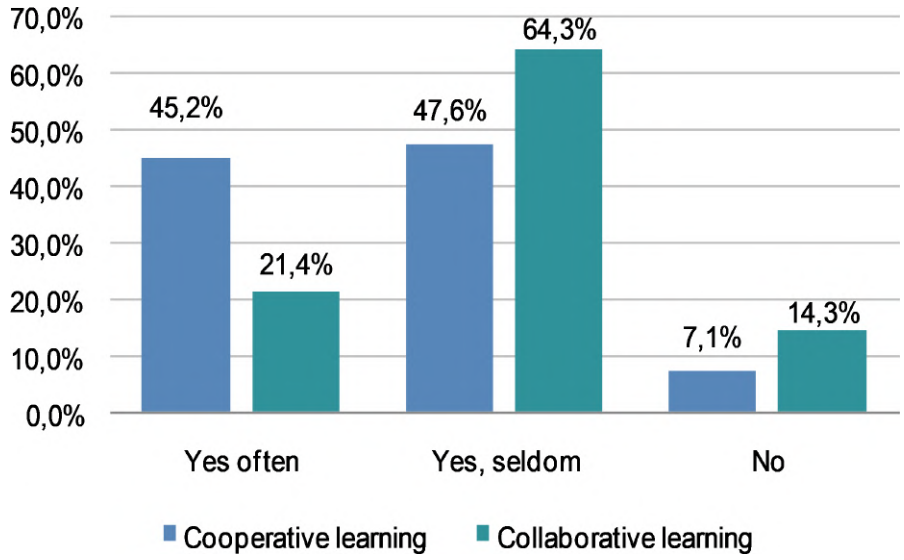


Figure 6: Bar chart visualizing the answers of respondents to the questions "Do you use cooperative learning methods in your teaching practice?" (a) and "Do you use collaborative learning methods in your teaching practice?" (b) (Answer options: Yes often; Yes, seldom; No).

which determines the structure of the group and largely lays the socio-psychological foundations of group dynamics. In collective learning, self-organization is not the dominant aspect, which is primarily manifested in the possibility of free choice of tasks and ways to solve them. Collective learning forms a fairly effective grid structure in a small group format, which is at the same time one-dimensional, rather rigidly determined and largely predictable. We consider this structure to be "social-intellectual", which determines the dominance of the social over the personal and intellectual and, accordingly, can be designed for the effective implementation of a certain not very high class and level of tasks. Hence, collective learning is a system that is quite efficiently and rigidly formed and maintained.

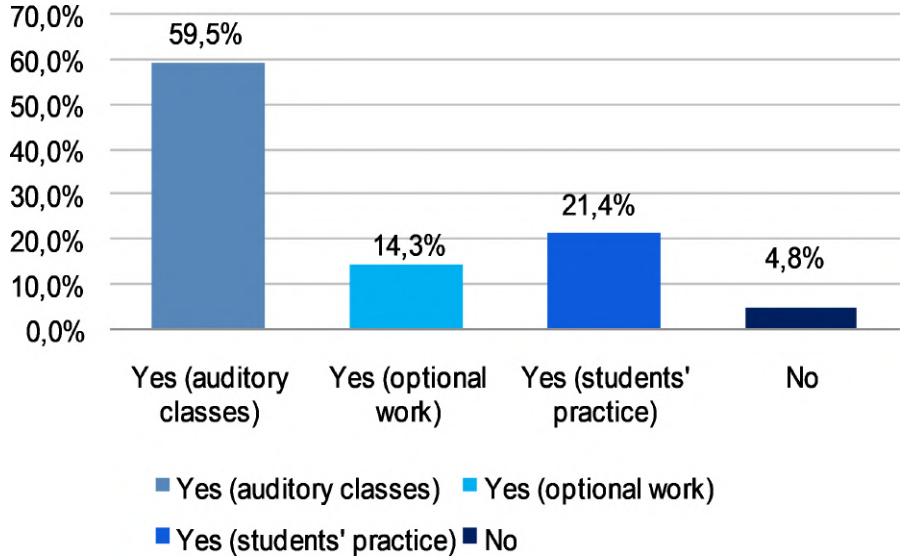


Figure 7: Bar chart visualizing the answers of respondents to the questions "Have you involved students in team project work? If yes, in what form was the project work carried out?" (Answer options: Yes (auditory classes); yes (optional work); Yes (students' practice); No.

In our opinion, self-organization and autopoiesis are important in collaborative learning, which contribute to the actualization of intrinsic motivation. This, in turn, forms the system as a multidimensional "socio-psychological-intellectual" grid, which determines the dominance of personal and intellectual

over social and, accordingly, can be designed for the effective implementation of different levels of tasks (including high). This structure is dissipative in its conceptual essence (it supports itself), having received the initial organizational and management "impulse".

Collective learning, in which the social aspect is distinct, can be seen as the first stage in the application of collaborative learning, which in its essence (despite being implemented in the format of group work) is personalized, intellectualized and socio-psychological.

During the research, it was found that only every 7th lecturer has the experience of training student teams to participate in team programming. Since the answers to the question "Do you prepare student teams for participation in team programming?" were distributed as follows: Yes (14.3%); No (85.7%). If we compare this with the fact that team programming is a specific and highly intellectual activity that requires both effective team and personal intellectual activity, we can suggest that collaborative learning is one of the most effective and congruent (in the sense of relevant) ways to prepare for team programming. Accordingly, if lecturers have little experience in preparing student teams to participate in team programming, they cannot fully appreciate the effectiveness and "socio-personal-intellectual" orientation of collaborative learning. This phenomenon is also indicated by the two graphs above. Among the methods used by university teachers in the process of preparing students for team programming, teachers named cooperative learning and collaborative learning.

The results of the study shown in the figure 8 (a) indicate a rather significant effectiveness of collaborative learning in solving relatively simple tasks, which is typical when using group work methods. It is well known that in a group, simple tasks are performed more efficiently than in an individual. This feature is also inherent in collective learning. In these cases systematic activity, synergistic effects, collective intelligence, goal setting, and external motivation are actualized.

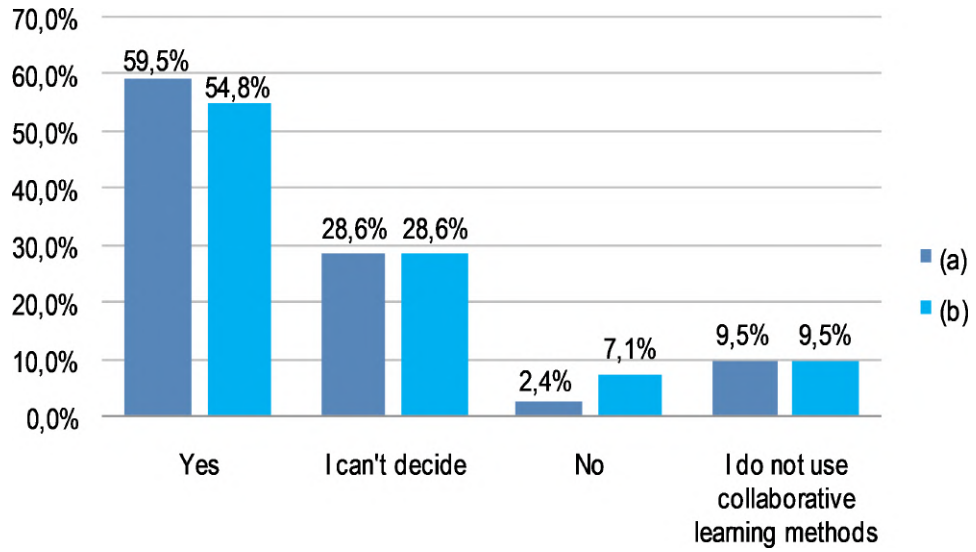


Figure 8: Bar chart visualizing the answers of respondents to the questions: (a) "When you used collaborative learning, did you observe an increase in the effectiveness of learning activities, which was manifested in solving relatively simple tasks?"; (b) "When you used collaborative learning, did you observe an increase in the effectiveness of learning activities, which was manifested in solving relatively complex tasks?" (Answer options: Yes; I cannot decide; No; I do not use collaborative methods in teaching).

As shown in figure 8 (b), the study's findings suggest that a fairly significant effectiveness of the use of collaborative learning in solving relatively complex tasks within team programming. Compared to the previous graph, which shows the effectiveness of solving relatively simple tasks, this graph indicates a slightly lower efficiency in the implementation of complex tasks. This reflects a well-known phenomenon, the essence of which is that working in a group does not always contribute to the effective solution of complex intellectual and creative tasks. This requires both group work and individual activity. At the same time, the rate of solving complex tasks is quite high – 54.8%, which indicates the effectiveness of collaborative learning as a group activity that simultaneously actualizes the intellectual

and creative potential of the individual. That is, both collective and individual intelligence are effectively manifested in collaborative learning.

The results presented in figure 9 imply that a significant aspect of collaborative learning is the formation of effective goal setting and understanding of the tasks that can be viewed as technology-oriented problematization.

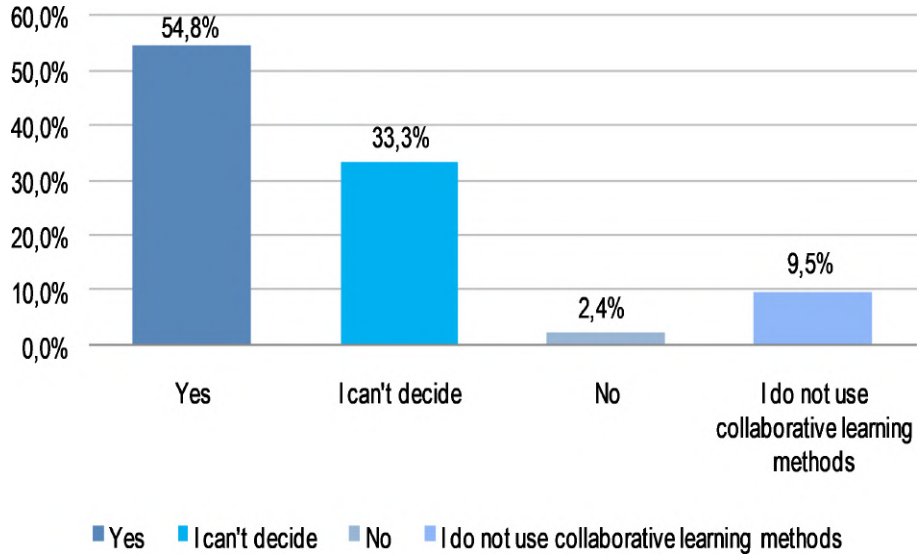


Figure 9: Bar chart visualizing the answers of respondents to the questions "Did the use of collaborative learning contribute to a better understanding of the tasks and the formation of effective goal setting?" (Answer options: Yes; I cannot decide; No; I do not use collaborative methods in teaching).

The figure 10 (a) reveals the emotional aspect of collaborative learning in the format of effective interaction in the group, which is 54.8%. Effective emotional interaction helps to consolidate the group, develop goal setting and communication, and form a collective mind.

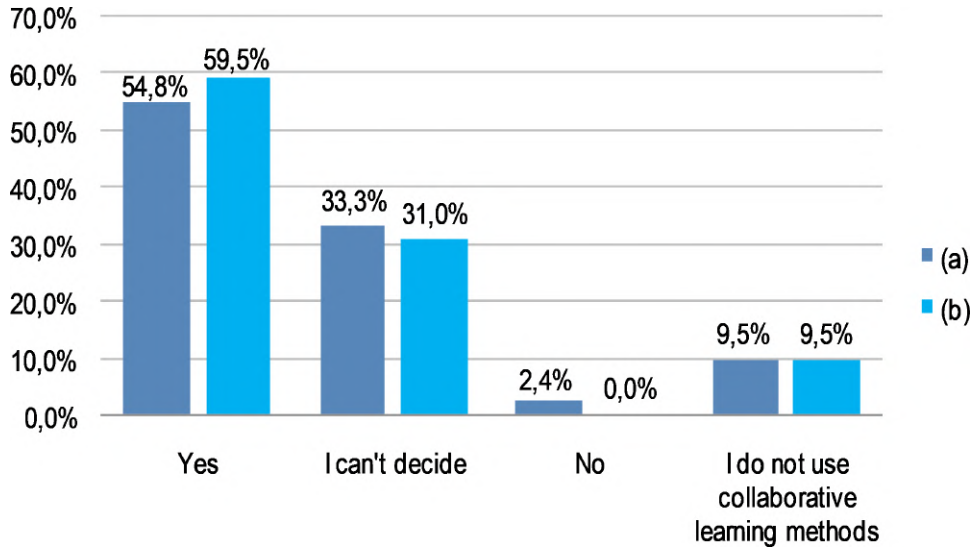


Figure 10: Bar chart visualizing the answers of respondents to the questions: (a) "Did the use of collaborative learning contribute to the formation of effective emotional interaction in the group?"; (b) "Did the use of collaborative learning contribute to the formation of effective cognitive interaction in the group?" (Answer options: Yes; I cannot decide; No; I do not use collaborative methods in teaching).

The figure 10 (b) shows the phenomenology of effective cognitive interaction in the group, which is quite high – 59.5%. This indicates that collaborative learning contributes to the disclosure of individual

intelligence, the formation of a collective mind and intellectual communication, which ultimately manifests itself in the effective solution of intellectual problems.

According to the data presented in figure 11, a fairly significant percentage (57.1%) characterizing the development of common values in the group's activities. These values are relevant because they represent an axiological basis that determines the consolidation of the group, its focus, goal setting, ethics of activity and, ultimately, the effectiveness of solving intellectual tasks assigned to the group.

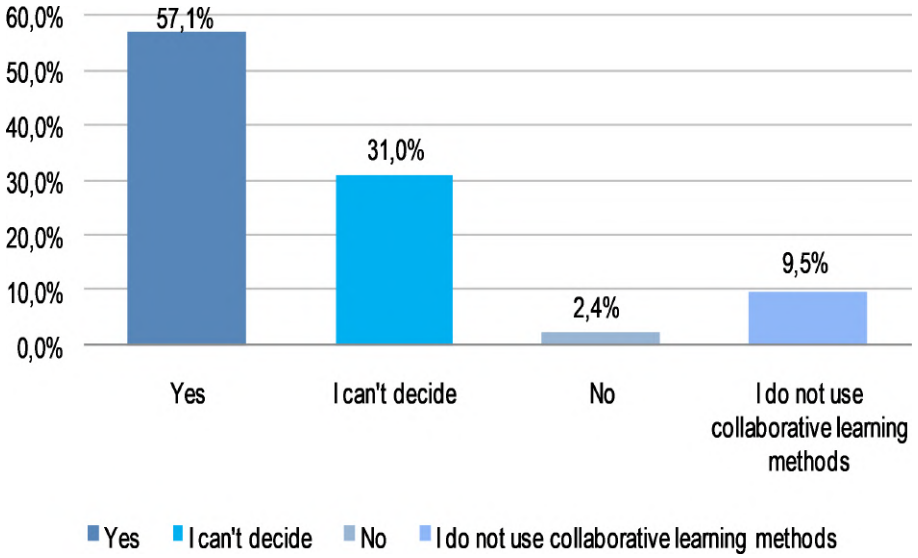


Figure 11: Bar chart visualizing the answers of respondents to the questions "Did the use of collaborative learning contribute to the formation of common values in the group?" (Answer options: Yes; I cannot decide; No; I do not use collaborative methods in teaching).

It is important to emphasize that, in summary:

- Quite often, cooperative and collaborative learning are used integratively.
- The use of cooperative learning as a basis and/or prerequisite for collaborative learning is typical.

In those cases in which collaborative learning is used, the capabilities of individual and collective intelligence, including emotional intelligence, are integratively actualized. Also, both external and internal motivation are effectively manifested, with the dominance of the latter. This helps to reveal the personal and creative potential of the participants.

Collaborative training activates the valuable dimension of a specialist as a creative and active person. Collaborative educational activity, thanks to the actualization of the personal-existential dimension of the individual, contributes to the internalization of the values of activity and personality. And also their transition into the axiological contexts of professional existence as an individual and a team. There is also a structuring and hierarchization of the specialist's values and their transformation into personal axiological systems. At the same time, the transition of values into value orientations and motivations is carried out. Accordingly, value orientations and motivations are those mental formations that contribute to the development, maintenance of direction and goal-setting of the individual. They are aimed at the performance of a certain specific task, which is considered as a significant component of life creativity and professional realization and self-actualization. There is also a concretization and practically oriented transformation of values and their inclusion in the scheme of activity, which can be simplified as "subject – action – object". That is, values under the influence of collaborative learning are transformed, concretized and, accordingly, become a prolonged regulator and stimulator of activity and a structure-forming factor in the development of professional subjectivity and an axiological-motivational prerequisite for creativity.

In cooperative learning, we believe that the above-mentioned axiological transformations are observed to a somewhat lesser extent. And values remain mainly external socio-psychological or worldview-philosophical prerequisites of activity.

A significant factor of collaborative learning is the actualization of spontaneity, freedom and responsibility as significant manifestations of the existential dimension of the individual. The specified aspects in cooperative learning are less pronounced due to the dominance of specifics and "plannedness" necessary to perform certain tasks. In cooperative learning, the dominance of the "spirit" of collectivism as such, which becomes a self-sufficient value, is also significant, rather than the focus on creativity, personality and its development and the final result, which can be achieved variably and creatively.

4. Conclusion

The concept of sustainable development as a system-organizing strategy for the development of humanity is primarily based on the concept of ecologically oriented human qualities (Aurelio Peccei). This determines the need to consider the anthropological, psychological and intellectual factors represented in the educational format as one of the determinants in the implementation of the concept of sustainable development. In this aspect, the actualization of the intellectual potential of both the individual and the group acquires special significance, an effective way of which is the use of collaborative learning.

There are many similarities between cooperative and collaborative learning, there are also significant differences. Compared to cooperative learning, collaborative learning involves a more intensive and multidimensional integration of the group, as well as a deeper and more specific and practically oriented understanding of the problem being solved by the group. Thanks to collaborative learning, a "collective mind" is formed in the group relatively quickly, which, first of all, increases the team's ability to effectively problematize, clarify, expand, and interpret a particular problem, while maintaining the integrity of its perception. Typical for cooperative learning is the distribution of certain tasks among team members, which they solve both independently and in consultation with others. In collaborative learning, although this distribution of tasks may also be present, it is mostly joint task performance that involves a certain change of performers, for example, by distributing and changing roles in the team. An important effect of collaborative learning, which is observed in comparison with cooperative learning, is the relatively equal distribution of performance indicators, which indicates the stability of the group, the effectiveness of its goal setting and focus on a particular task, the formation of a subject of collective action and, in general, effective group dynamics aimed at achieving the set tasks.

Collaborative learning is considered as one of the modern effective group learning directions, the phenomenology of which is integratively revealed: socially oriented in the format of group dynamics and intellectually and psychologically as a way of developing creativity and intelligence by revealing personal potentials. Collaborative learning as a social and intellectual-psychological technology forms a system that can be represented as a multidimensional "social-psychological-intellectual" grid. This "social-psychological-intellectual" grid can be considered as a dissipative structure capable of forming synergistic effects and capable of self-maintenance, self-organization, and transformation.

Based on the conducted theoretical and practical studies, it can be said that collaborative learning, which is implemented in the format of group work, is at the same time personalized, psychologized, intellectualized, and socio-psychological. When using collaborative learning, the processes of self-organization and autopoiesis and actualization of internal motivation are the leading systems. The innovativeness and democratization of collaborative learning makes it possible to organically and synergistically integrate the individual and collective mind and, accordingly, to obtain significant educational, creative and intellectual effects when it is applied.

In order to form general ideas about the features of the use of collaborative learning and its significance and place in the training of future specialists in information technologies, namely in the process of team programming, a study of university lecturers was conducted using a questionnaire developed by the authors. When analyzing the results of the study, it is determined: that teachers actively use collective learning, which to some extent we consider as a stage in the use of collaborative learning; when organizing collaborative learning, classroom work is often used and the issue of free choice of tasks is actualized to a somewhat lesser extent; the majority of the studied teachers have relatively little experience of training student teams to participate in team programming, which, despite the significant

interest in this educational technology, indicates insufficient understanding and practical application of it; when using collaborative learning, there is a certain (insignificant) decrease in efficiency when solving relatively complex tasks compared to simple ones, which corresponds to the researched regularity of intellectual work in group work; collaborative learning contributes to the formation of common group values, effective goal setting and understanding of assigned tasks, effective emotional interaction, and also develops group consolidation and forms goal setting, communication, effective cognitive interaction and collective mind, and reveals the potential of individual intelligence.

According to the survey, 21.4% of respondents often use collaborative learning in their educational practices. This technology is used episodically and rarely in 64.3% of cases. This quantitative distribution indicates the significant importance of collaborative learning in the professional activity of teachers as an important innovative and psychologically and personally oriented educational technology among other modern and traditional methods and technologies of education. This also speaks of the relative novelty of collaborative learning as a technology, which, in comparison with cooperative learning, requires from the teacher for its implementation appropriate professional, including psychological, training, as well as innovative thinking of personal-oriented visions.

The use of collaborative learning by teachers to solve relatively simple tasks in 59.5% of cases and to solve relatively complex tasks in 54.8% of cases indicates its ability to equally actualize the intellectual and creative potential of both groups and individuals. The indicated effectiveness of intellectual activity, which is revealed, first of all, when solving complex tasks, is related to the fact that collaborative learning in 54.8% of cases contributes to the development of effective goal setting and a better understanding of the essence of tasks by students, and is also caused by effective emotional interaction, which is determined in 69% of cases and effective cognitive interaction, which is observed in 59.5% of cases. The indicated effectiveness of intellectual activity is also due to the actualization of the value dimension of both the individual and the group. Accordingly, it is determined in 57.1% of the formation of common values.

Thus, the use of collaborative learning in the process of training future information technologies specialists provides an opportunity to: share knowledge and experience among team members, which allows for faster learning and development; improve communication skills and the ability to work in a team; increase the motivation and involvement of each participant in the learning process; to receive feedback and correct mistakes in the learning process, and therefore potentially improve the results that the team achieves.

Declaration on Generative AI: The authors have not employed any Generative AI tools.

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Harnessing online services for creating augmented reality enhanced comics in primary education

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Abstract

This article explores the current state and practical solutions for addressing the readiness of primary school students and teachers to utilise cloud services for creating augmented reality (AR) enhanced comics. The didactic potential of comics as an educational tool is clarified, and a comparative analysis of modern cloud services, programs, and applications for comic creation is presented, highlighting their advantages and disadvantages. The functionality of AR programs for creating comic-based content (Vuforia, EasyAR, Maxst, ARCore, AR.js, 8th Wall) is analysed. A survey of teachers reveals the most popular cloud services, including Pixton, Marvel HD, and Comica. Algorithms for developing educational materials using these cloud services to create AR-enhanced comics are presented. Readiness levels for using cloud services to create AR-enhanced comics (elementary, basic, and creative) are developed, and the current state of readiness among teachers and students is characterised. Educational and methodological support has been developed for implementation in university education and teacher professional development. Prospects for further research, including monitoring the readiness of students and teachers to use cloud services for creating AR-enhanced comics following the introduction of the authors' educational and methodological support, are discussed.

Keywords

cloud services, augmented reality, comics, educational technology, primary education, teacher training

1. Introduction

In the rapidly evolving landscape of primary education, modern teaching methods are increasingly focused on employing non-traditional, interactive, and playful approaches to engage young learners. As traditional lessons often prove less effective, teachers are compelled to seek innovative means and forms of instruction. The role of the teacher is transforming, necessitating the ability to organise captivating lesson-plays, lesson-journeys, and lesson-quests. Among these emerging educational tools, comics stand out for their potential to simplify, visualise, and virtualise complex information through a blend of forgiveness and visual playfulness. The visual nature of comics enhances the level of learning, offering advantages over time-limited media such as movies and animation, which present language and actions at a rapid pace. In contrast, the progression of time in comics is determined by the reader's pace of eye movement across the page, allowing for a personalised speed of information processing. As Chykalova [1] note, comics serve as a tool for developing imagination, fantasy, and the skills to clearly and concisely formulate and express opinions, as well as to distinguish the main ideas from the text. Engaging with comics contributes to the development of 21st-century skills among younger schoolchildren, such as emphasising the essential and collaborating in a team.

The effectiveness and productivity of educational technologies incorporating comics have been demonstrated in recent years, with materials containing or based on AR technology proving particularly popular, as evidenced by the authors' pedagogical experience. However, an analysis of the actual practice of the educational process in primary schools reveals a lack of high readiness among teachers to apply comics in pedagogical activities, particularly those enhanced with AR. This can be attributed

AREdu 2024: 7th International Workshop on Augmented Reality in Education, May 14, 2024, Kryvyi Rih, Ukraine

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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

CEUR-WS.org/Vol-3918/paper160.pdf

to a shortage of methodological developments on the use of AR-enhanced comics in training and the limited capacity of teachers to develop and utilise such materials using cloud services. Consequently, this highlights another significant problem: the preparation of future primary education teachers to use cloud services for creating AR-enhanced comics in their professional practice.

In today's digital age, the integration of innovative technologies such as AR-enhanced comics into primary education has the potential to revolutionise the way young learners engage with and absorb complex information. By harnessing the power of visual storytelling and immersive experiences, educators can create captivating learning environments that foster creativity, critical thinking, and collaboration. However, the successful implementation of these technologies hinges on the readiness and competence of teachers to effectively utilise cloud services for developing and deploying AR-enhanced comics in their classrooms.

1.1. Related work

The importance of comics as a learning tool has been highlighted in several studies [2, 3, 4, 5, 6, 7, 8, 9]. Of particular relevance to this work are studies focusing on the use of digital technologies as a means of effective visualisation in the creation and application of comics. The works of [10, 11] analyse modern software such as Bitstrips, Comic Life, Pixton, MakeBeliefsComix, Cartoon Maker, and Graphix Comic Builder, examining their functions, characteristics, capabilities, and limitations. Fragments of the use of these software in the implementation of the educational process are presented. Zerkina et al. [12] explored the possibilities of using Pixton to form the ICT competence of engineering students using a project approach. Different didactic possibilities of the specified cloud service are given in the studies [13, 14, 15]. Weber [16] considered the use of cloud-based graphic narrative software in medical ethics teaching. In addition, the theoretical and practical aspects of data visualisation and the use of digital technologies for this purpose are presented in the works [17, 18, 19, 20]. The use of augmented reality to work with comic book-based teaching material is the subject of research in [21, 22, 23].

1.2. The objective of the research

The purpose of this article is to explore the possibilities of using online services to create AR-enhanced comics in the educational process of primary school.

The study aims to address the following objectives: to identify the most popular cloud services for creating comics among teachers and characterise them; to reveal the algorithms for developing educational materials in cloud services for creating AR-enhanced comics; to investigate the current state of readiness of future teachers and students to use cloud services for creating AR-enhanced comics; and to develop educational and methodological support for the use of these cloud services in the educational process.

2. Research methodology

To conduct this study, the following methods were employed: theoretical (analysis and synthesis of psychological, pedagogical, and methodological sources, programs, handbooks, systematisation and generalisation of theoretical material; study of experience with the research problems; clarification of the basic knowledge of the studied problem), empirical (pedagogical observation, interviews with teachers and questionnaires, writing methodological recommendations, formulating conclusions and determining the sequence of research), and statistical (Pearson's criteria for identifying the real state of readiness of students and teachers for the use of cloud services).

The study was conducted at Borys Grinchenko Kyiv Metropolitan University and 11 schools in Kyiv, Ukraine. The study involved 28 primary school teachers and 84 students specialising in "Primary Education" from years 1-4 of study.

3. Results and discussion

3.1. Analysis of cloud services for creating comics

Comics serve as a new, effective, and democratic tool for primary school teachers in the formation and comprehensive development of initiative and creative personalities among schoolchildren. Combining visual and playful qualities, comics can satisfy the interests and meet the peculiarities of the course of mental processes in modern junior schoolchildren, representatives of the generation, to prevent the occurrence of stress during the study [1]. There are numerous online services and apps available for creating comics. However, not all of them are suitable for teachers to organise work in class. Most services are paid, too complex, require special knowledge and skills, or their content is not designed for a children's audience. Finding the right program, service, or app is difficult and time-consuming, which teachers often lack.

Lack of time for training is also a problem because the service must not only be found but also learned to work with and know how and when to use the developed materials.

In this study, we focused on functional, free, and most importantly, simple services that provide easy access to programs for both teachers and students (table 1).

Each of these online services contains a certain number of templates grouped by types:

- People (children, teens, young men, adults, elderly people);
- Animals;
- Things;
- Transport;
- Special characters;
- Backgrounds (school, forest, city, houses, historical and mythological views, nature, etc.).

Table 1
Modern online services, standalone and mobile applications for creating comics.

Online services		*Need to be uploaded*	
StoryboardThat	Price: Free basic version; Language: English.	Comic Life	SW: Windows/macOS; Price: Free version – 30 days; Language: choice.
Pixton	Price: Free; Language: Italian.	Krita	SW: Windows; Price: Free; Language: choice.
Make Beliefs Comix	Price: Free; Language: choice.	MediBang Paint Pro	SW: Windows/macOS; Price: Free; Language: choice.
Debate365	Price: Free; Language: English.	*Mobile apps*	
Canva	Price: Free; Language: Ukrainian.	Comica	SW: Android/iOS; Price: Free; Language: choice.
Write Comics	Price: Free; Language: English.	Comic and cartoon maker	SW: Android/iOS; Price: Free; Language: choice.
Marvel HD	Price: Free; Language: English.	MomentCam	SW: Android/iOS; Price: Free; Language: choice.

When creating a plot, you can choose the expression of the face, the position of the body, the mood of the hero, change his appearance, clothes, etc.

It should be noted that in table 1 you can also get acquainted in detail with the main characteristics of modern online services, programs, and applications for creating educational comics, which can be used not only for working online but also for working in the classroom with the ability to print material.

All offered by us online services, programs, and applications for creating comics can use instant translation in Ukrainian and maintain it in the services themselves. Using these services, the teacher can diversify the form of educational material presentation, will be able to convey complex ideas and concepts using minimal artistic means, and will be able to organise not only face-to-face but also distance learning qualitatively and interestingly. It is also possible to organise work with services not only individually but also in a group format.

The services are quite simple, so schoolchildren will be able to work with them. Most of them do not require users to register, and they can start working with them right away. Talking about the advantages of using these services, we can note the following:

- Availability of services in material terms (most are free or have the possibility of using the trial/free version);
- Simple interface (intuitive);
- Use of templates (each service has its template database for use);
- The ability to create a completely new product (the ability to download own resources is provided);
- Dissemination of materials (it is possible to disseminate or embed the created materials of the author);
- Versatility (materials can be used to work in any lesson for individual or frontal work, both online and printouts). It is also worth highlighting the disadvantages:
- Other-language interface (most programs are foreign, but there is a possibility of using Google instant translation);
- Preliminary training of teachers and students;
- Conversion (not all file formats are supported; their size is limited).

The creation of training materials such as comics using the specified software can be supplemented with AR elements. The experience of implementing the educational process using AR also allows us to highlight programs for developing and working with AR.

- Vuforia can easily create marker-based AR, markerless-based AR, and cloud-based AR. Provides sufficient support to create an application for minor tasks. In particular, it allows you to recognise 2D and 3D objects, English text (the vocabulary contains over 100,000 words, or you can use your dictionary) and allows you to play videos.
- EasyAR offers its next-generation SDK, which has some features such as SLAM, 2D–3D screen tracking and recording, cloud-based object recognition, and unlimited recognition requests. In addition, the free version can store up to 1000 tags on the device.
- Maxst offers two types of augmented reality software: Maxst AR SDK 2D and Maxst AR SDK 3D. The first tool can only recognise 2D images, and the other is much more powerful and can track 3D objects. The Maxst AR 3D SDK has features such as SLAM, physical engine effect, and occlusion effect. The Maxst AR SDK 2D features multiple image recognition (up to 200 images per channel), video zoom, instant object tracking, image and marker tracking, and a QR/barcode scanner.
- ARCore is not only supported on Android, but also on iOS devices, allowing you to develop cross-platform AR applications. Features of the application include: in addition to identifying key points, ARCore can detect flat surfaces, and can also estimate the average illumination around them; determining the size and location of vertical, horizontal, and inclined surfaces; tracking movement according to the position of the phone, accurate placement of virtual objects; assessing light and understanding depth.
- AR.js is an open-source AR SDK based on JavaScript. Can create AR scenes based on markers. The tool comes with an A-Frame and three.js extension that works with any smartphone, regardless of its OS version, including Android, iOS, and other. Markers are stable but limited in shape, colour, and size.

- 8th Wall provides support for markers (Image Target), World Effects, Face Effects, SLAM. Video recording, light evaluation, and relative zoom function are available. Can be used in combination with Unity and Unreal engines.

When choosing modern online services, programs, and applications for creating comics, as well as AR, which a teacher can use in his educational activities to study in primary school, we were guided by three main criteria:

- Service availability;
- Ease of use;
- Functionality.

As a result of a survey of primary education teachers, it was found that all services meet such requirements, but separately, for working with primary school students, the following services are most often distinguished: for teachers – Pixton; for schoolchildren's work – Marvel HD, and the app installed on the gadget – Comica.

3.2. Algorithms of development of educational materials in cloud services for the creation of comics

Let's start with Pixton comic book designer that allows you to create your stories almost from scratch. Allows you to customise models, background images, people's postures and emotions, and other image details, allowing you to create interactive comics. We start working at Pixton by choosing the type of user (teacher, pupil, parent, or business). We are interested in the user-teacher. A sign-up window appears, indicating that you can sign up for free. After registration, the user is flipped to the configuration panel. Suggested three steps to set up the service.

Step 1 – Watch an introductory video where pupils who work with this service share their impressions. After watching the video, click the "Next Step" button.

Step 2 – Familiarise yourself with the process of creating comics in the Pixton service. Press the button "Create a comic book" and go to the Pixton work field. The work field contains a page panel, four comic creation toolbars, a search bar, and a comic display area. In the first toolbar, select the background of the comics (for example, the pupil's room) and the main characters (the girl). Use the search bar to enter the name of the desired background or character (in English) or use the suggested groups (under the search bar). You can also upload your own materials – the camera icon under the comic book display area. Go to the toolbar to focus the image. Select the desired type of drawing (for example, "to the right"). Next, go to the text panel and enter the lines of the characters. This can be direct language (round dialog window), thoughts (window-cloud), shout (orange window), and whisper (dotted window). In the face setting panel, choose the desired emotion, for example, a thoughtful look. There is also the option to choose the character's look. The last panel is the position setting of the hero's body. Here you can choose the posture, the direction of movement and the possibility of holding objects in the left or right hand. In the upper-right corner, click the "Finish" button and go to the third step of the settings.

Step 3 – Enter the name of the comic book and choose a class. Next, the service offers to make a teacher's avatar, which is created similarly to the comic, following the instructions offered by Pixton. Then the user is moved to the personal account, where the existing 4 sections (created classes, student comics, class photos and printed versions of comics) are also displayed on the right-hand side, where the "Link for pupils" button is displayed, from which the teacher can invite students to the virtual classroom.

A fragment of work with the program is shown in figure 1.



Figure 1: Example of a comic created using the Pixton online service.

The following program, which was chosen by us, is excellent for both individual and group work of junior school students. It is not required to register and fill out various forms here. There is an opportunity to create the simplest comic with ready-made templates.

Write Comics – is the easiest service to create comics and stories. After all, this is just one page where you can set all the parameters of your plot: characters, background; text box.

We start by entering the name of the comic. Scroll the cursor further and select the characters in

our story, dragging them to the desired location in the comic book image area. Next, we choose the background, the place where the events of the story take place and enter the lines of the characters. Press the "Finish" button, the comic book is ready (figure 2).

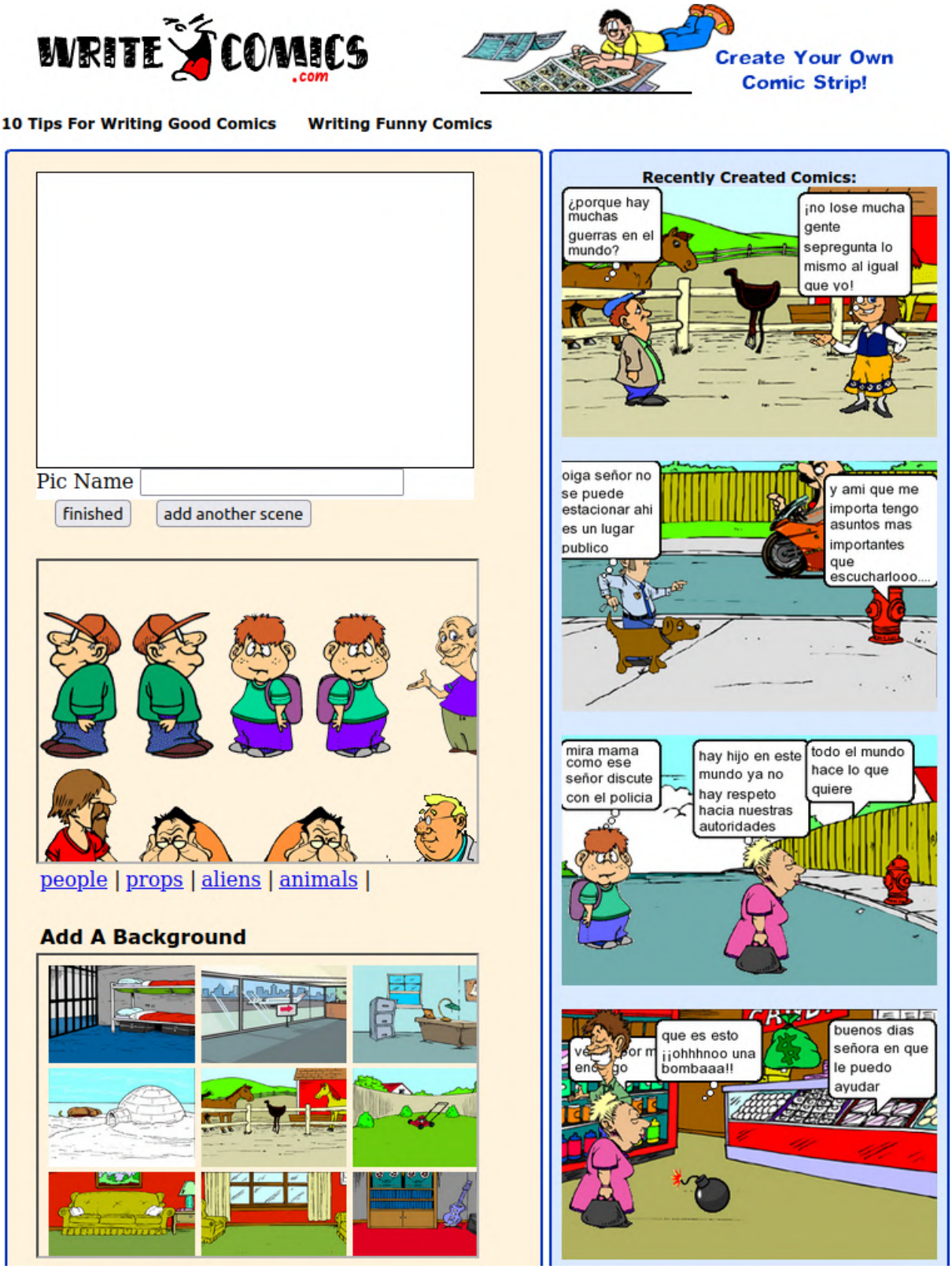


Figure 2: Fragment of work with the Write Comics service.

The next program that can be used to create comics in primary school is Comica. This is an app that

you can use to create a comic from your own photos. First, you need to download the app and install it on your gadget. It can be done in any user-friendly service (for example, in the Play Market).

Open the app and view the menu: Gallery – processing of one photo in the comic book editor; Camera – instant photo creation; Multi is the comic book editor.

Select "Multi", set the number of episodes in the picture (for example, 3 pictures), click on the field and select a photo from the gallery. We process the photo in the photo editor and choose the comic style. We individually adjust brightness and contrast, if needed. Next, we select the stickers and the comic book elements that the user needs. We do the same thing with the other two photos and create an episode of the comic. Download the comic book or share it (figure 3).

These services are quite convenient and understandable. The key value of resources is that in each program there is an opportunity to use ready-made templates of drawings, characters, backgrounds, signs, objects, etc., and to adjust them as needed. Working with these applications does not require special knowledge and skills, which is why it is an immense advantage. After all, even junior school students will be able to work in the service.

However, a significant disadvantage is that the developers of these online services and applications do not provide any instructions on how to work with them, so users have to deal with the way applications work by themselves.

3.3. Determination of the real state of readiness of teachers and pupils to use cloud services to create comics with AR elements

As a result of a survey of teachers, it was found that many people "do not know where to start" or consider it an impossible mission to create comics on their own. Many teachers know about cloud services, where you can find ready-made developments, but cannot select the appropriate comic for a particular learning situation or lesson. Most teachers do not know how to create comics, including with AR elements, using cloud services. These and some other circumstances keep many teachers from introducing this kind of teaching activity into teaching practice.

The analysis of the student survey also shows that within the informatics disciplines at the university, the use of cloud services for creating comics is not given due attention (table 2).

Table 2
Levels of readiness of teachers and students to use cloud services to create comics with AR elements.

Level	Characteristics of the level	Teacher skill level requirements
Elementary	Lower awareness of cloud services use, in particular AR. The teacher knows fragmentarily about the peculiarities of working with these cloud tools, but does not have a goal to learn how to create comics, cannot relate to the pedagogical expediency of their use.	Using the pedagogical capabilities of comics at the starting level, for example, conducting a lesson with a multimedia presentation or a ready-made animated resource already developed by a bulk product with AR elements. Using didactic materials with the help of cloud services, already developed and ready for the lesson comics.
Basic	Uses cloud services to create comics and AR at the demonstration level (presentations, pictures, slides). Formulates the request in relation to the specific topic of the upcoming lesson. Can associate with the pedagogical feasibility of their use. Can create his own comic book by analogy, including with AR elements, using step-by-step instructions.	Designing tasks for pupils using cloud services that involve the use of comics, including with AR elements in class and outside classroom hours, for example, for homework tasks related to search and selection of information, including on the Internet.
Creative	Actively uses cloud services to create new and use ready-made comics with AR elements. Disseminates its developments and participates in network communities.	Integrated use of cloud services and modern educational technologies: integrated lessons, project activities of pupils using comics with AR elements. Advise colleagues on using and working with resources to create comics with AR elements.



Figure 3: Comic Book Editor Comica.

As a result of the experiment, we found the willingness of teachers and students to use cloud services to create and use comics in educational practice. Appropriate criteria and levels of readiness have been identified and developed.

Level 1 – elementary, characterised by superficial knowledge of working with cloud services to create comics with AR elements;
Level 2 – basic, characterised by a focus on the use of cloud services at the demonstration level;
Level 3 – creative, characterised by the active use of cloud services to create comics with AR elements.

As a result of the questionnaires developed by us on the theoretical principles of using cloud services, tasks on working with cloud services and the results of self-assessment, the real state of readiness of teachers and students to use cloud services for creating comics with AR elements was revealed (table 3).

Table 3
The state of teachers and students readiness to use cloud services to create comics with AR elements.

Level	Students (84 persons), %	Teachers (28 persons), %
Elementary	63.1	67.9
Basic	26.2	25.0
Creative	10.7	7.1

According to the results of the study, students and teachers showed approximately the same ability to use cloud services. Most students (63.1% of the total number of respondents) and teachers (67.9%) have an elementary level of readiness. Only 10.7% of students and 8% of teachers reached the creative level.

The results confirmed the problem of the preparation of future primary education teachers for the use of cloud services for creating comics with AR elements in professional activities.

To compare the results obtained, we used the Pearson criterion χ^2. For this purpose, statistical hypotheses are formulated:

H0 – the level of students' readiness to use cloud services does not exceed the level of teachers' readiness;
H1 – the level of students' readiness to use cloud services exceeds the level of teachers' readiness.

The obtained empirical value of the Pearson's criterion $\chi^2 = 0,932$ we compared with the tabular values (for the number of degrees of freedom 2 (table 4).

Table 4
Critical value of the Pearson criterion χ^2.

χ^2 $(p = 0.05)$	χ^2 $(p = 0.01)$
5.991	9.21

Thus, we accept the hypothesis H0 that the level of students' readiness to use cloud services does not exceed the level of teachers' readiness.

Note that given the insufficiently large sample size, we certainly do not claim a strong scientific justification for the state of this readiness in the context of the activities of all teachers and students of primary education. The data obtained, rather, indicate an overall trend regarding the research problem and require finding ways to improve it.

3.4. Educational and methodological support for teachers

As a result of a survey of teachers, we identified fundamental problems with the use of cloud services. Among them, we can note the lack of time for self-education and learning.

Taking into account this problem, Iryna R. Chopyk have developed a website, where the necessary information was collected and methodological recommendations were prepared on the organisation of the teacher's work using cloud services for creating comics in classes in primary school (https://blogger090.wixsite.com/comics).

This educational website helps primary school students and teachers improve their own competencies in using cloud services to create comics.

Thus, the work of the website is aimed at helping the primary school teacher to create their own development of interactive educational content, as well as using them in lessons in primary school. The website contains 4 sections:

1. Homepage;
2. “About the project”;
3. “For teacher”;
4. Feedback.

The homepage provides a brief description of the project, links to articles, and a contact window where anyone can contact the author of the website if needed. At the top, the site menu is presented, which is intuitive and allows the user to go to the following categories (figure 4).

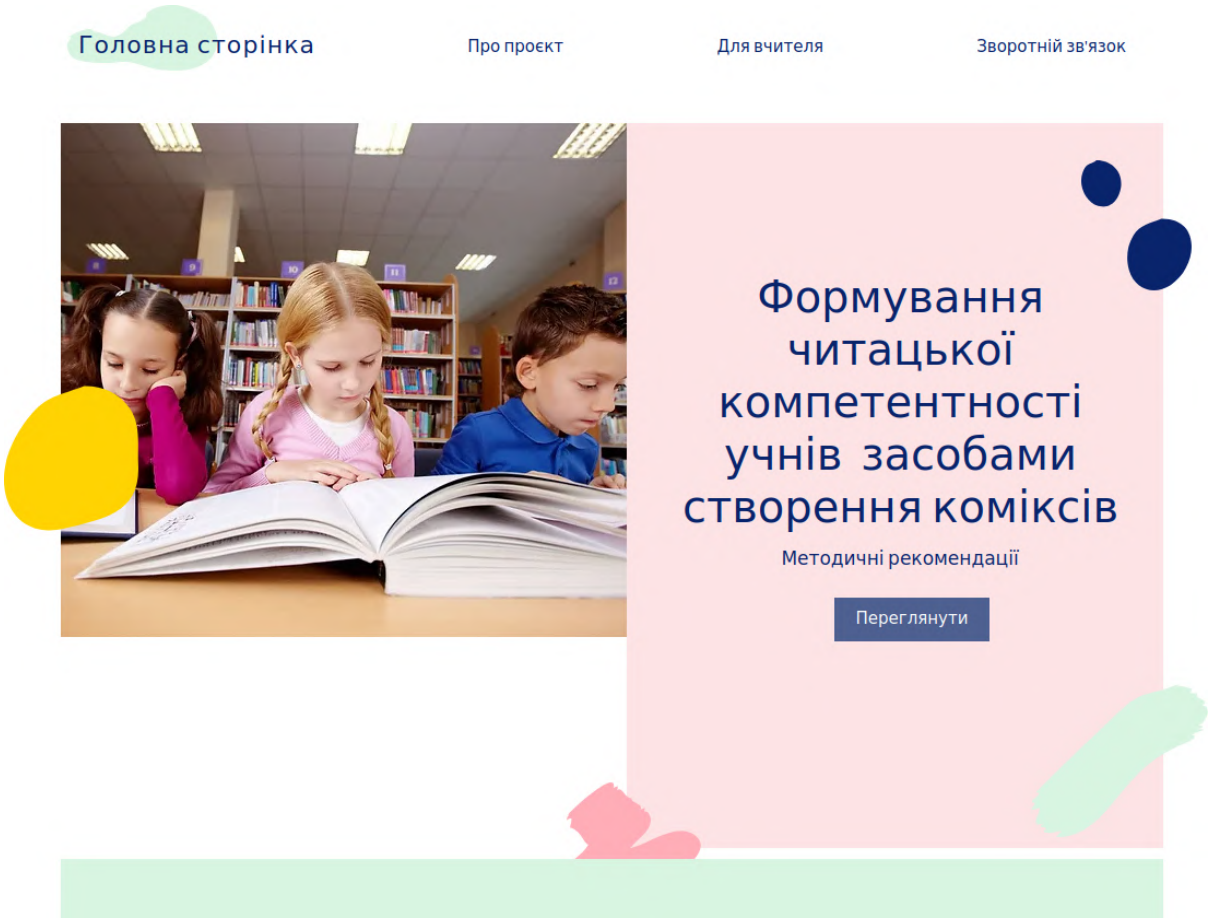


Figure 4: The main page of the developed website.

The section “About the project” provides basic information about the master’s study, the purpose of creating the site, what its work is aimed at, and short theses “Here you will learn”:

- What is a tutorial comic?
- How to work with online services to create comics?
- How to organise work in the classroom using the comic book technique?

The category “For the teacher” contains three subdivisions:

- “Theoretical information”, which provides information about what is the process of reading and its importance in human life, reveals the essence of basic concepts, describes the reasons for the popularity of educational comics, and identifies the strengths of their application in education;

- "Services", where the user can find a list of free and available online services for creating their educational comics. Separately, in the section, there are links to instructions for the described services.
- "Methodological recommendations", which provides practical advice and methodological recommendations for working with the technology of using comics in primary school. The unit provides a step-by-step description of the technology of working with comics, describes the preparatory work with pupils, defines the rules for selecting the subject of comics, provides examples of building educational tasks for working with comics and links to online resources for creating educational comics.

Looking at the "Services" section in more detail, users can see the rating from the TOP-3 online services for creating educational comics. This rating of tools was formed based on three key criteria: functionality, affordability (all services are free) and ease of use of the service for both teachers and pupils.

Each presented service contains instructions for use, which the user will be able not only to view but also to download to himself on a PC as a MS Word document.

Each service title contains a link to its main page, which the user of the site will be able to start working on creating his own educational comic, using the downloaded instructions and methodological recommendations presented on the educational website.

Thus, the work of the educational website is aimed at helping teachers of primary education in the development of relevant educational comics using online services Pixton, Write Comics and Comica for conducting lessons in primary school, as well as for methodological support of educators.

4. Conclusions

1. It has been established that the use of AR-enhanced comics in primary school is one of the effective didactic means that increases children's interest in learning and allows for the simplification, visualisation, and virtualisation of complex information. As a result of the analysis of modern cloud services, programs and applications for creating comics, their advantages are highlighted: the availability of services in material terms; a simple interface; the use of templates; the possibility of creating a completely new product and distributing materials; versatility. The major disadvantages have been clarified: a foreign language interface, the need for preliminary preparation for working with them; conversion. The functionality of AR programs for creating content based on comics (Vuforia, EasyAR, Maxst, ARCore, AR.js, 8th Wall) is analysed. As a result of a survey of 28 primary school teachers, considering availability, ease of use and functionality, the most popular cloud services are highlighted: for teachers – Pixton; for pupils – Marvel HD and the app installed on the gadget – Comica. Algorithms for the development of educational materials in these cloud services for the creation of comics are presented.
2. The levels of readiness for the use of cloud services for creating AR-enhanced comics (elementary, basic, creative) are highlighted. It is established that most teachers and students have an elementary level of readiness. To improve the real state of readiness of teachers and students to use cloud services, an educational website has been developed. Its goal is to help primary school students and teachers improve their competencies in using cloud services to create comics. Methodological recommendations on the use of comics in primary school using digital technologies have also been developed.
3. The next step of the study will be the implementation of the developed methodological recommendations in the practice of university education, in the system of teachers' certification training, as well as further monitoring of the readiness of students and teachers to use cloud services to create AR-enhanced comics in primary school.

Acknowledgments: The research was performed within the framework of a complex scientific topic of the Department of Computer Science and Mathematics of Borys Grinchenko Kyiv Metropolitan University "Mathematical methods and digital

technologies in education, science, technology", DR № 0121U111924.

Declaration on Generative AI: The authors have not employed any Generative AI tools.

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Leveraging augmented reality in a mobile application for effective advertising of educational services: an efficiency analysis

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Abstract

This paper examines the efficacy of a mobile application utilising augmented reality (AR) technology for advertising educational services at the Faculty of Information and Computer Technologies, Zhytomyr Polytechnic State University, Ukraine. The application, developed using Vuforia Software Development Kit in Unity, was deployed during career guidance activities. To assess its impact, data pertaining to applicants who submitted documents, viewed AR advertising, enrolled at the university, and their competitive scores were analysed using descriptive statistics and exploratory analysis techniques. The results demonstrate a notable increase in interest among applicants who interacted with the AR application, affirming its effectiveness in career guidance. The findings suggest that AR-based mobile applications can be a valuable tool for enhancing the appeal and information content of advertising materials, ultimately boosting applicant engagement. Future work aims to extend this application to all faculties within the university.

Keywords

augmented reality, vuforia, descriptive statistics, data analysis, advertising efficiency

1. Introduction

The rapid advancements in human-computer interaction have paved the way for innovative user interface paradigms. The widespread adoption of virtual reality has introduced the related concept of augmented reality (AR) into scientific discourse [1, 2]. While current user interface technologies primarily focus on human-computer interaction, AR leverages computer technology to enhance the interaction between humans and the real world [3, 4].

AR has emerged as a highly relevant research area, describing the process of augmenting existing reality with virtual objects. With the increasing prevalence of mobile devices, AR is poised for significant growth. By 2025, nearly 75% of the global population and almost all smartphone users are projected to be frequent AR users [5].

In the context of education, the majority of institutions currently offer both state-funded and commercial programs. The rising number of private educational establishments has intensified competition, compelling universities to employ relevant marketing tools and instruments to attract students, reinforce their market position, and enhance competitiveness.

The combination of mobile devices and AR technologies presents compelling advantages for advertising educational services, including informing applicants and their parents, creating a positive impression, increasing university recognition, and enhancing the effectiveness of career guidance activities.

This study aims to evaluate the effectiveness of a mobile application, UniAd, developed by specialists from the Department of Computer Science at Zhytomyr Polytechnic State University, Ukraine. The application employs AR technology to advertise the educational services of the Faculty of Information

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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

CEUR-WS.org/Vol-3918/paper162.pdf

and Computer Technology (FICT). The research objectives include analysing data collected during career guidance work, conducting intelligence and statistical analyses across various indicators, and drawing conclusions based on the findings.

2. Literature review

The application of AR technologies in science education was explored at the AREdu 2020 conference [6]. Bilous et al. [7] emphasised the potential of AR application development as a promising research area for students, outlining the essence, directions, and advantages of AR technology in the educational process.

Several studies have demonstrated the current state and relevance of AR [8, 9]. Hordiienko et al. [10] presented a software application that utilises AR to provide a detailed representation of solar system objects, employing scaled dimensions to accurately depict the distances between planets. He et al. [11] reported enhanced English learning outcomes in children through the use of an AR application that displays visual representations of English words using a mobile camera. Vakaliuk et al. [12] showcased the possibilities of AR technology in creating a local history software application, "Monuments of the city of Zhytomyr", which was tested during city tours with elementary school students, resulting in increased interest in studying the history of their native city. Zhou et al. [13] introduced a mobile application that promotes lifestyle engagement in AR, enabling users to combine practical skills and visuals for enhanced multidimensional intelligence development.

The application of AR in contemporary chemical education and its potential for enhancing students' chemistry research projects were investigated by Nechypurenko et al. [14]. Krainyk et al. [15] explored the development of a historical guide based on AR technology, while Hruntova et al. [16] theoretically substantiated the use of AR technology and its features in higher technical educational institutions. The feasibility of AR in STEM education in Ukraine was demonstrated by Bilyk et al. [17].

Beyond the educational context, AR has been employed in various domains. Jung et al. [18] described an application for virtual tours of Jeju Island, enabling users to explore cultural heritage even in remote regions. Wang et al. [19] examined the popularity of AR mobile applications across four categories: games, advertising, videos, and shopping, concluding that AR mobile games are the most frequently used. Ozdemir [20] studied the role of virtual and AR for accessibility and marketing in tourism, highlighting both strengths and weaknesses. Wang et al. [21] analysed the status and benefits of AR technology application in domestic logistics. Osadchyi et al. [22] explored the possibilities of using innovative AR technologies to form the viability of future specialists. Hu et al. [23] investigated the attributes of theatrical performances using AR in theme parks, finding a positive effect on visitors' nostalgia and emotional arousal.

Carmigniani et al. [24] examined the current state of AR technologies, systems, and applications, addressing the challenges and requirements for successful mobile AR systems. Young and Koo [25] discussed the development of university library services using virtual and AR technologies, suggesting considerations for their implementation. Wyss et al. [26] reported a highly positive attitude and interest among students towards AR technologies.

Park [27] introduced ARLooper, an iOS AR application for multiplayer audio and performance, exploring the potential of mobile AR technology in creating new music interfaces and collaborative audiovisual experiences.

Based on the analysis of recent publications and the experience of using AR technologies, it can be concluded that AR has significant potential for application in education, particularly for advertising purposes.

3. Theoretical background and system design

3.1. Augmented reality technology

Augmented reality (AR) is a concept that describes the process of complementing existing reality with virtual objects. AR is evolving rapidly and is poised to become as significant a technological advancement as the Internet or mobile devices. It serves as a powerful tool for brands to attract consumers, enhance communication, and strengthen consumer confidence. The camera transforms AR from a gaming technology into a comprehensive experience that enriches people's lives. AR is already widely recognised as both interesting and useful, promoting rapid implementation and growth, with untapped demand for an increased number of AR applications [5].

AR can be implemented using applications for smartphones and tablets, AR glasses, stationary screens, projection devices, and more. The essence of AR technology lies in combining the real image with its virtual complement and outputting the final image on a visualisation device.

The foundation of AR technology is an optical tracking system. There are several options for using AR technology: marker-based and markerless. Marker-based technology is easier to use, as it is simpler for the camera to recognise and provides tighter binding to the location for the virtual model. This technology works almost seamlessly, often using a sheet of paper with a special image as a marker. The type of image can vary greatly and depends on the image recognition algorithms employed.

In this work, the advertising booklet of the Faculty of Information and Computer Technologies of Zhytomyr Polytechnic State University, Ukraine, is used. Before using the booklet, it needs to be marked with Vuforia to activate the application. The booklet image must be less than 2 megabytes in size, with a clear picture or photo. It is uploaded to the Vuforia website to obtain a rating. A rating of 1-2 stars is not recommended, as the speed and quality of recognition will be very low, potentially leading to incorrect program reviews. The booklet used in this study has a rating of 4-5 stars, indicating that recognition in the software application does not require much time and will accurately display the reproduced information about the specialty.

Marker technology using Vuforia creates static markers and uses them to enable object activation (figure 1).

3.2. Creating 3D objects

To create the UniAd mobile AR application, a number of graphics were developed using Blender. The main, albeit most time-consuming, model is the university building. In addition to the main facility, several other objects were created, including trees with animated leaves that move in the wind, walking human models with gait animation, benches, lanterns, and a fountain model located at the main entrance to the university (figure 2).

Furthermore, a number of 2D models serving as buttons were added to the mobile application, allowing users to select certain actions (figure 3).

3.3. Design and implementation of individual system modules

The Unity engine was used to create the program, leveraging its component-oriented system for working with objects. Interactivity and gameplay in Unity are based on three fundamental blocks: GameObject objects, components, and variables [28]. Any object in the application is a GameObject, including characters, light sources, special effects, scenery, and more. Components determine the behaviour of game objects to which they are attached and control them.

Figure 4 presents a precedent diagram demonstrating possible user actions when using the mobile application. The precedent corresponds to a separate service of the system, determines one of the options for its use, and defines the typical way of user interaction with the system. Usage parameters are commonly employed to determine system requirements.

An activity diagram was used to describe the behaviour of the mobile application (figure 5). The diagram reflects the dynamic aspects of system behaviour, essentially serving as a flowchart illustrating

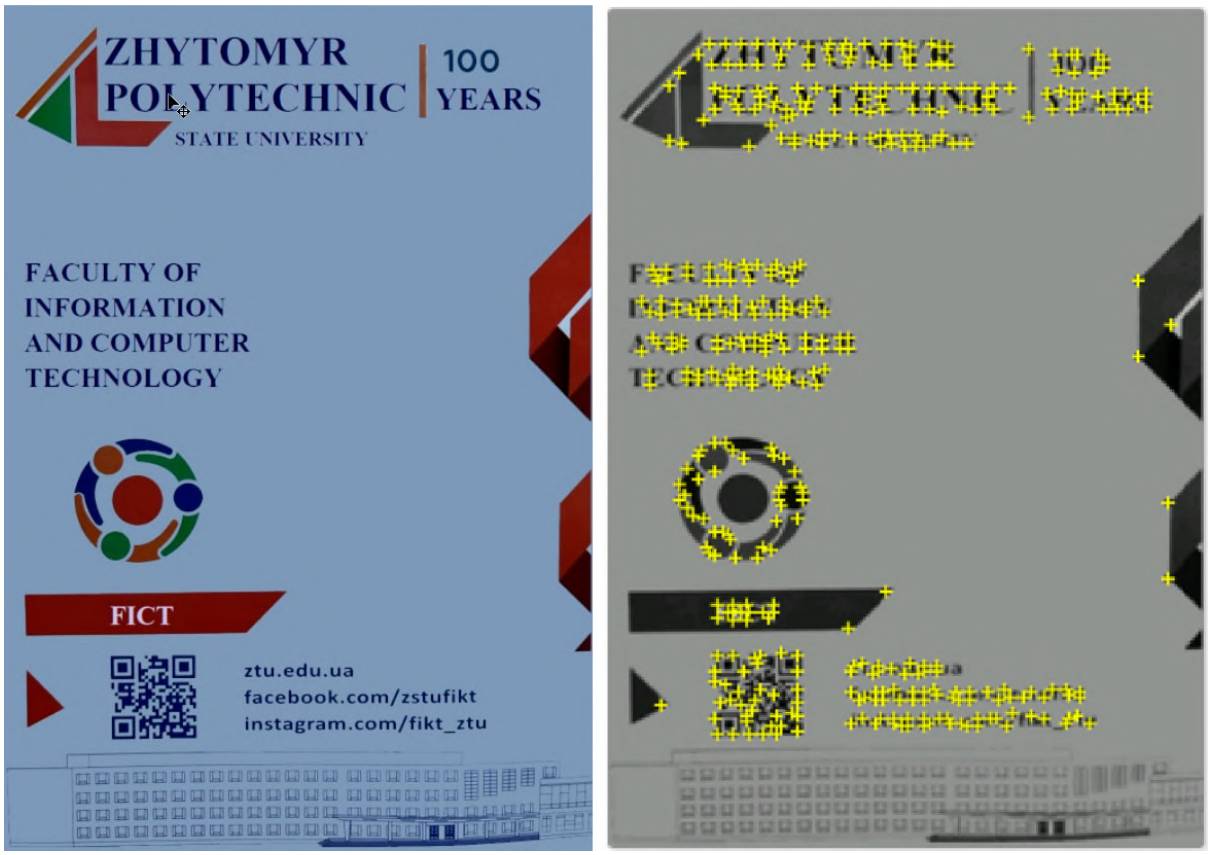


Figure 1: Creating targets on the booklet for the UniAD application.

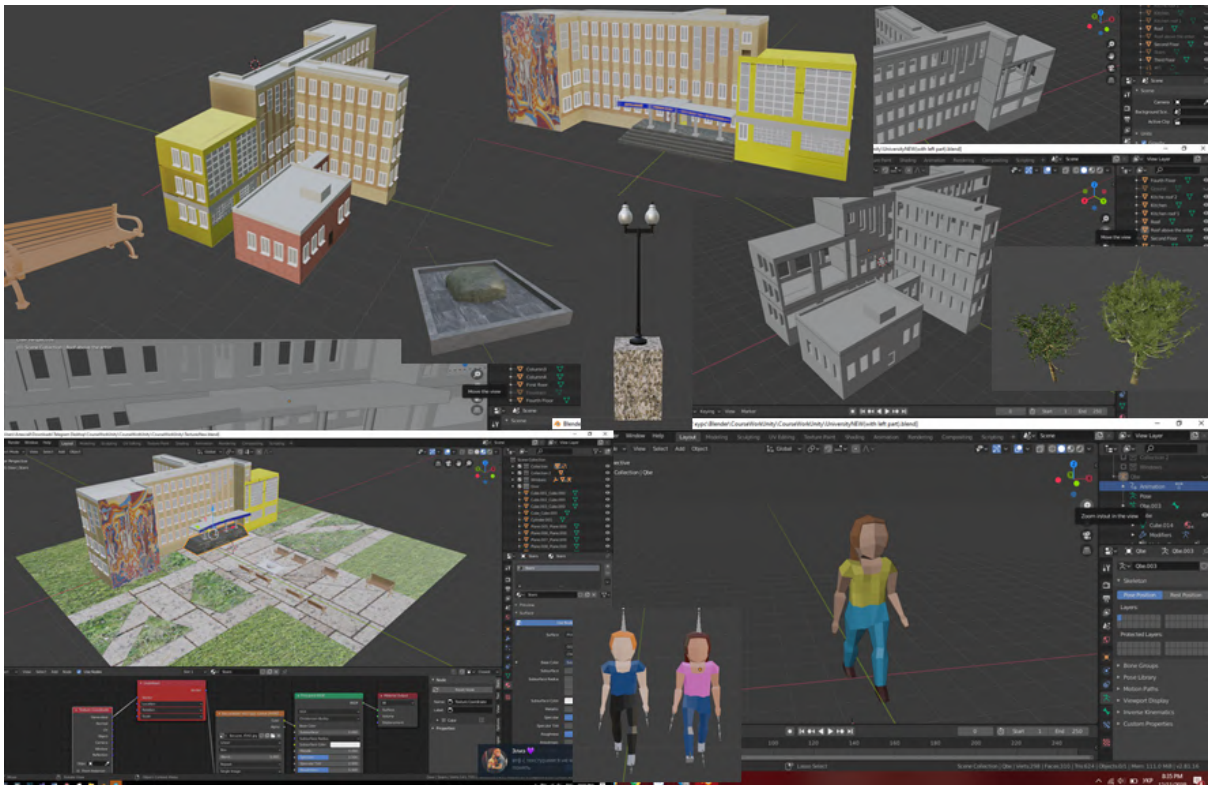


Figure 2: 3D models developed in Blender.



Figure 3: Buttons.

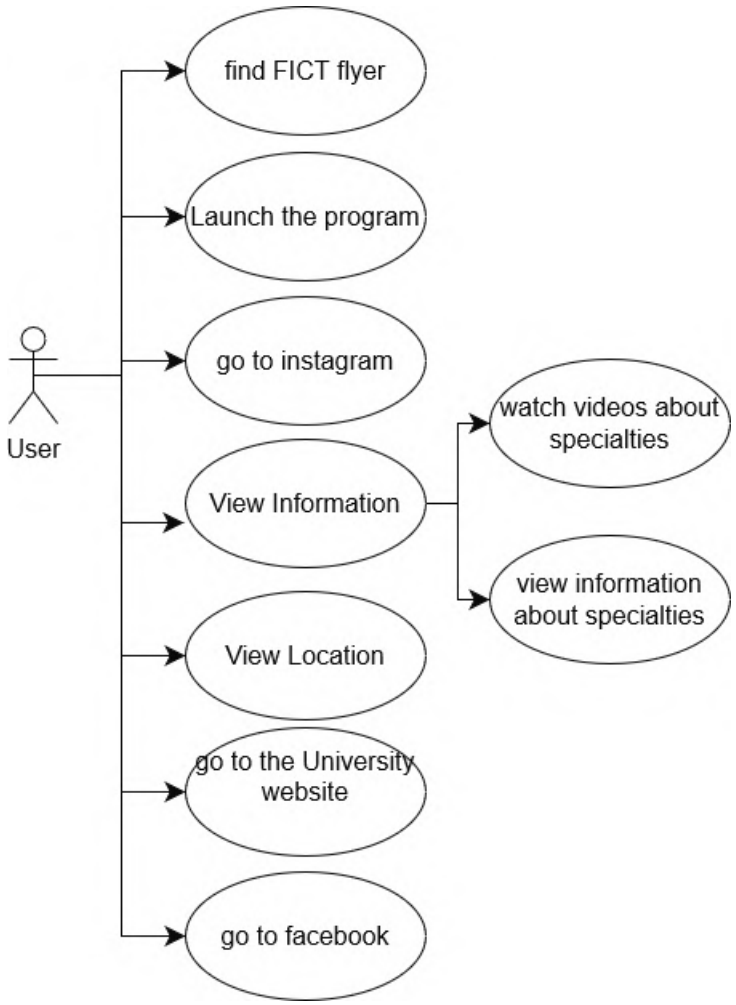


Figure 4: Use case diagram of the mobile application.

how control flow moves from one activity to another.

3D application simulation was created using the Blender development environment. The main model is the university building, with auxiliary objects such as bushes, benches, trees, and a fountain, some of which are partially animated. Many animations were created in the mobile application, including a 360-degree rotation of the university building, bone animation of student 3D characters moving near the university, and leaf movement on trees simulating wind. The Animator Controller, created by Unity, allows managing a set of animations for GameObject and switching between them when certain conditions are met.

Figure 6 illustrates the general algorithm of the system. Using an AR camera, focus is placed on the booklet of the Faculty of Information and Computer Technology. If the appropriate markers are found in the image, the “Start” button is displayed.

Unity supports C# scripting, following either the traditional object-oriented approach or the information-oriented approach.

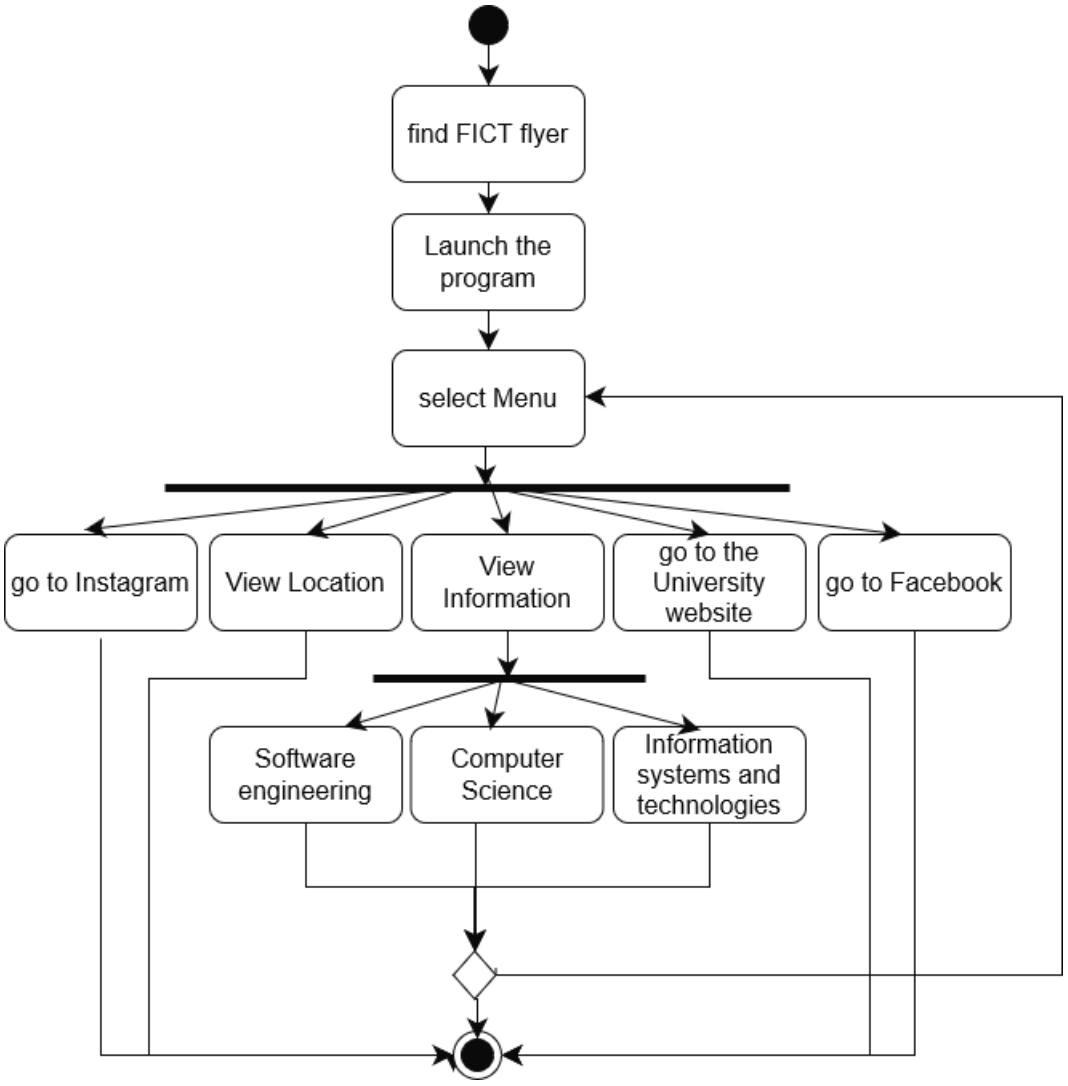


Figure 5: Activity diagram.

3.4. Mobile application interface

The application, implemented using Unity and Vuforia, can be used on devices with Android operating system version 10 and higher, requiring 210 MB of free memory. The interface is quite simple, with management carried out using the smartphone camera and the faculty booklet on which the user points the camera.

After launching the mobile application and pressing the "Start" button, calm music starts playing, and the animation of the university's appearance begins. Near the university, there are people walking, trees with rustling leaves, benches, lanterns, a fountain, and an inscription above it. Another "Menu" button appears on the screen. Figure 7 shows the program's image after clicking the "Start" button.

Users can view the university model by rotating the paper advertisement, as well as enlarge or reduce the institution's image. They can also open a drop-down menu to access additional university resources, such as the main university website, Instagram, Facebook, and Google Maps, indicating the location of Zhytomyr Polytechnic State University, Ukraine.

Pressing the "I" button opens seven cards, each representing a separate specialty at the faculty (figure 8). The cards display the specialty name, number, preferences, subjects, or interests. At the bottom of each card is a "View animation" button, which, when pressed, replaces the card with sprite animation related to the main activity studied in that specialty. Figure 8 shows an animation depicting an IT professional creating software, reflecting the essence of the specialty 121 "Software Engineering".

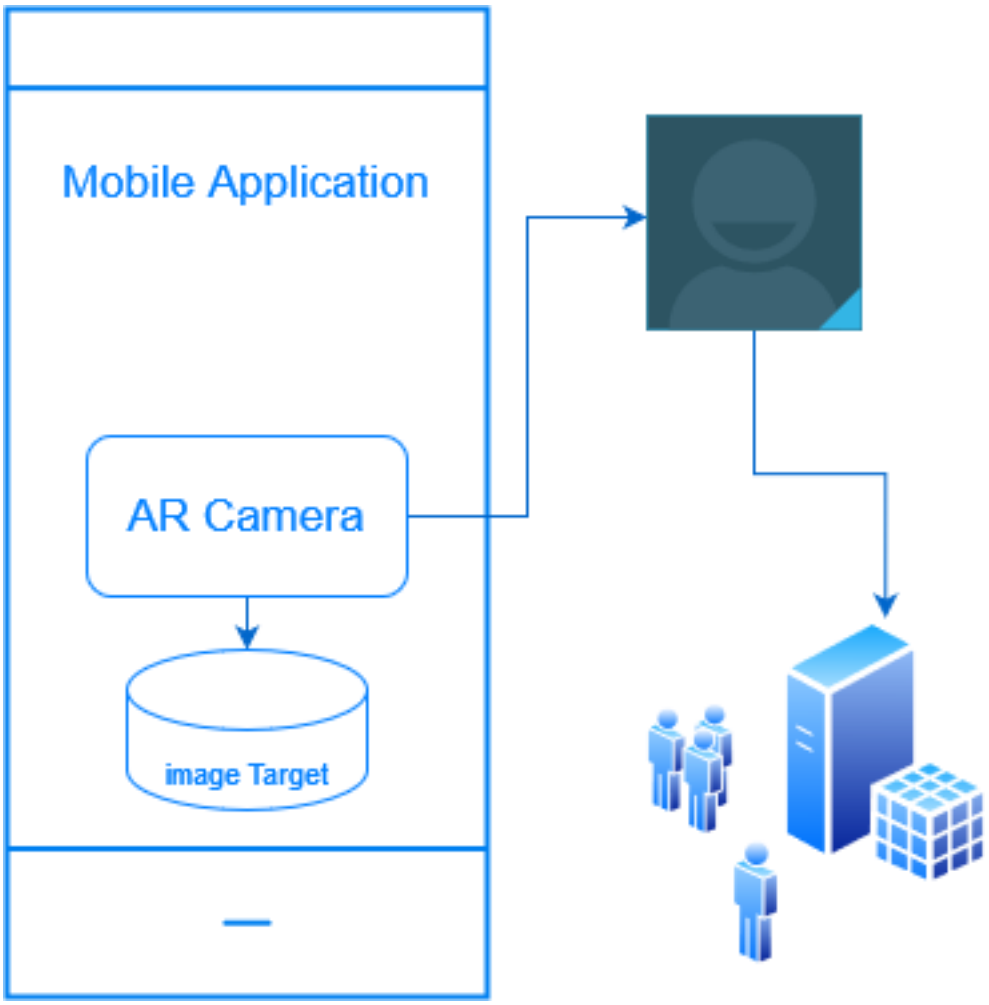


Figure 6: Scheme of project elements and their functionality.

By swiping the screen to the left, users can see all the animations and cards. To close the card view, the user must click on the "I" icon again.

When the user moves the camera away from the paper advertisement, all objects, music, and sounds are lost. To view the program again, the camera needs to be pointed at the paper advertisement once more.

4. Results

The application was intensively used during the career guidance work of the Faculty of Information and Computer Technology in 2021. During this process, a set of data was accumulated, which formed the basis for the analysis.

The data set, in CSV format, contains 1086 records represented by the following fields: submitted documents, saw AR advertising, entered the university, and competitive score. Among these, three fields are categorical data (0 or 1, saw advertising – 1, did not see – 0) (figure 9).

Descriptive statistics were used in the initial stages of the analysis. Measures of central tendency revealed the following indicators: the minimum value for the competitive score is 125 points, and the maximum is 200 points, with a range of 27 points. The arithmetic mean indicates that the "typical" score in the dataset is approximately 160.76, suggesting that most applicants have a fairly high competitive score. Spearman's rank correlation established a connection between competitive score and admission, as well as a small relationship between admission and ad viewing. The distribution of observations



Figure 7: General view of the program after pressing the Start button.

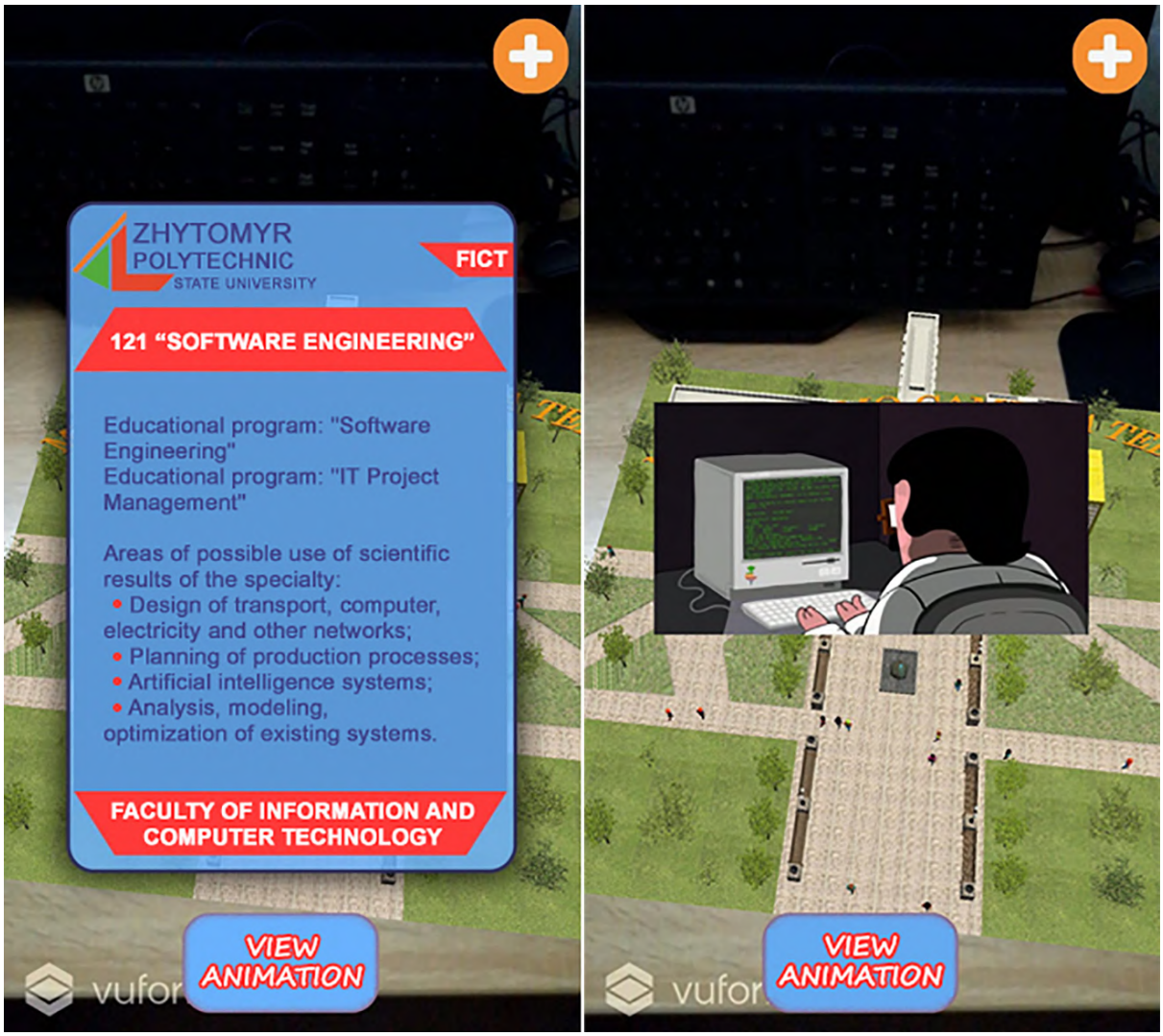


Figure 8: The result of pressing the "I" button.

	video_pres	sex	entered	competitive_ball	speciality
0	1	1	1	175	125
1	1	1	1	172	125
2	1	1	1	175	125
3	1	1	1	162	122
4	1	1	1	165	125
5	1	1	1	183	125
6	0	1	0	145	122
7	0	1	0	149	125
8	0	1	0	144	126
9	1	1	1	142	121
10	0	1	0	182	121

Figure 9: Fragment of the data set.

showed the following data: the first quarter is 152, the second quarter is 162, and the third quarter is 166. The standard deviation of the competition score is 13.32.

After profiling the file, it was determined that out of all applicants who submitted documents, 630 (58%) saw advertising. The majority of applications (60% or 652) were submitted for specialty 121 "Software Engineering", followed by 23.8% (259) for specialty 122 "Computer Science", 6.9% (75) for specialty 125 "Cybersecurity", 5.5% (60) for specialty 123 "Computer Engineering", and 3.7% (40) for specialty 126 "Information Systems and Technologies".

Out of all the applicants, 374 became students of the Faculty of Information and Computer Technology of Zhytomyr Polytechnic State University, Ukraine.

Figure 10 shows the general schedule of all applicants, those who enrolled, and those who saw the advertisement. The results indicate that not everyone who used the mobile application enrolled at the Faculty of Information and Computer Technology of Zhytomyr Polytechnic State University.

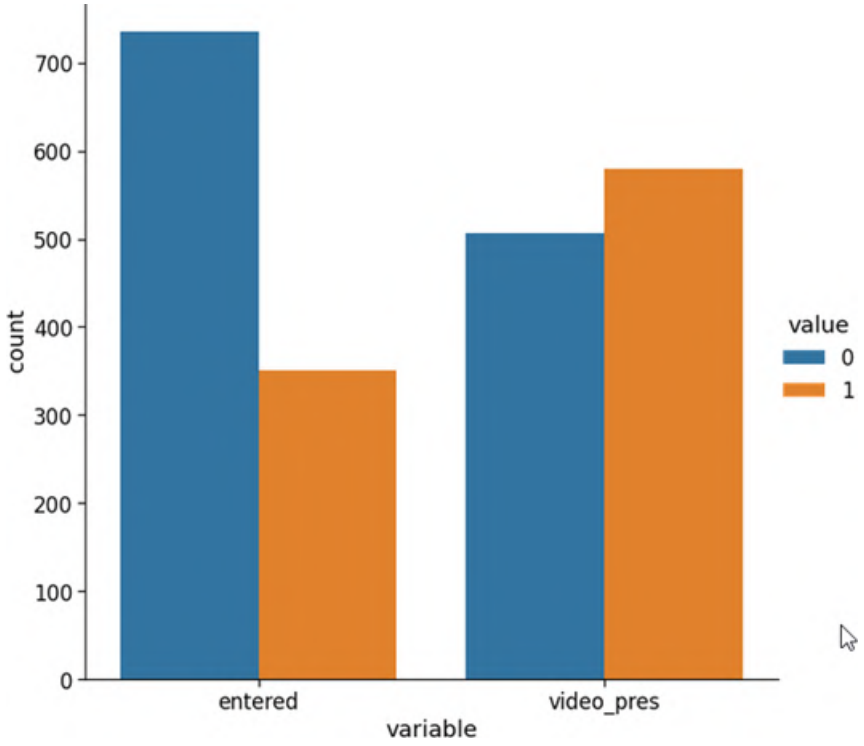


Figure 10: General schedule of all applicants, those enrolled, and those who saw the advertisement.

Figure 11 presents the data for the target variable "entered". Sample elements according to the value of the target variable are divided into two graphs, showing the number of applicants who did not enroll in FICT but saw advertising and those who saw advertising and enrolled in FICT. The schedule demonstrates that for both values, the number of applicants who saw advertising is higher, indicating increased interest in specialties at the university due to the search conducted before admission.

Figure 12 presents a histogram showing the data on advertising views using the application and the number of students enrolled in terms of FICT specialties. Interestingly, in specialty 122 "Computer Science", the number of enrolled applicants is higher than those who viewed the advertisement, despite the specialty's focus on augmented reality technology, which forms the basis of the created and researched UniAd mobile application. A more detailed analysis of the data for specialty 122 revealed that a significant number of students came from regions other than Zhytomyr (Lviv, Luhansk, Kyiv, Khmelnytsky, Rivne regions) and did not have the opportunity to use the application, thus not being reflected in the collected statistics. The coverage of a larger number of geographical regions in Ukraine has a significant influence.

The results show a significant number of applicants who saw the advertisement but did not enroll, which can be attributed to various factors, such as a low competitive score (figure 13). The passing score

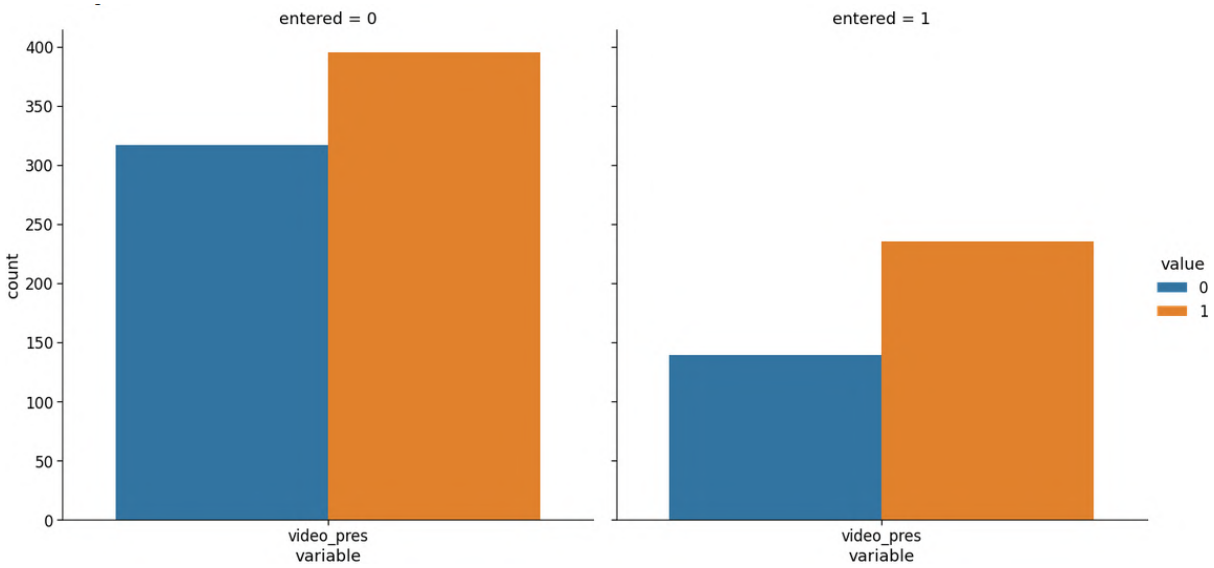


Figure 11: Data on the target variable “entered”.

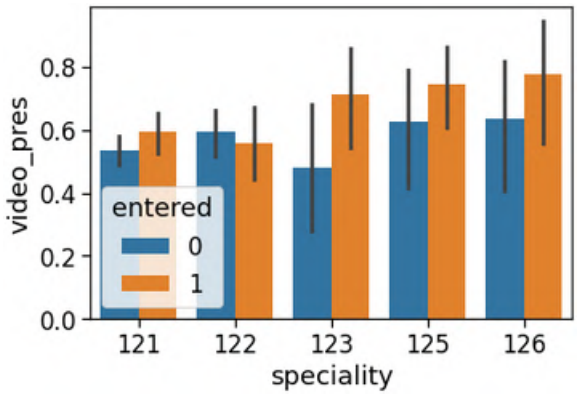


Figure 12: Histogram of advertising views and specialties entered.

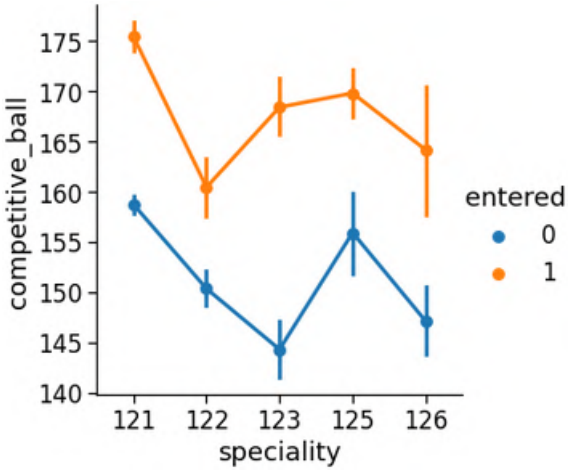


Figure 13: Data on the competitive score of applicants by specialties.

for admission was quite high and varied for each specialty, creating significant competition. The graph in figure 13 establishes the relationship between categorical and continuous variables, with vertical segments indicating the data portion for a particular category.

Another factor influencing admission is the lack of government-funded places for new specialties, leading applicants to seek other specialties or universities.

Considering the data in the context of gender, as shown in figure 14, a much smaller number of female applicants to technical specialties can be observed. In contrast, the girls' competitive scores vary between 154-176, which is above the mean, with a lower standard deviation compared to the total. It should also be noted that girls show more interest in specialties 121 "Software Engineering" and 122 "Computer Science".

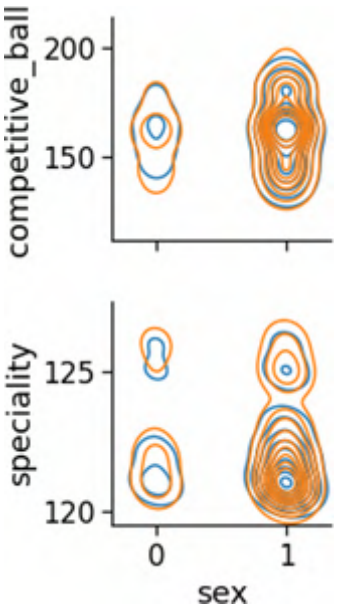


Figure 14: Diagram of advertising views by gender.

Based on the analysis of the data set, it can be concluded that advertising services using a mobile application based on AR technology are effective. Such applications attract applicants by providing information about specialties in an interesting way. Textual information is not always perceived qualitatively and in full, whereas the information presented in animated videos briefly represents the essence of the specialty, improving perception.

Methods of descriptive statistics and exploratory analysis were used for the analysis, implemented using the Python programming language, specifically the NumPy, Pandas, Seaborn, and Matplotlib libraries.

5. Conclusions

This study investigated the effectiveness of a mobile application for advertising educational services at the Faculty of Information and Computer Technologies of Zhytomyr Polytechnic State University. The analysis was conducted using data collected during career guidance work, with metrics including the number of applicants who submitted applications by specialty, the number of applicants who used the mobile application, competitive scores, and the number of enrolled applicants.

The results of the study demonstrate the appropriateness of using the developed mobile application. This is evidenced by the increase in first-year student enrollment across all specialties of the faculty in 2021, with the number of submitted applications exceeding the licensed volumes by specialty [29].

Therefore, we conclude that the use of augmented reality technology is suitable for promoting the educational process and advertising educational institutions. This approach undoubtedly increases applicants' interest and enhances the level of information perception about faculty specialties, achieved through diversity, interactivity, and visual presentation of information.

The mobile application was tested at the Faculty of Information and Computer Technologies of

Zhytomyr Polytechnic State University, Ukraine. In the future, it is planned to expand the application for use by various faculties and publish it in the Play Market.

Moreover, the effectiveness of the AR application in conveying information about specialties suggests that it can serve as a powerful tool for career guidance [30]. By presenting educational content in an interactive and visually appealing manner, universities can help applicants make more informed decisions about their future academic paths. This is particularly crucial in the context of technical specialties, where the complexity of the subject matter may deter some students from considering these fields.

However, the study also reveals some challenges that need to be addressed to maximize the impact of AR in education marketing. The lower number of applicants who viewed the advertisement for specialty 122 "Computer Science" compared to those who enrolled highlights the importance of expanding the geographical reach of such initiatives. Universities should strive to make their AR applications accessible to a wider audience, perhaps by exploring remote access options or collaborating with schools and educational institutions in different regions.

Furthermore, the gender disparity observed in the data underscores the need for targeted efforts to encourage more female applicants to pursue technical specialties. While the higher competitive scores of female applicants indicate their strong potential, universities must work towards creating an inclusive environment that nurtures and supports their interests in these fields.

Declaration on Generative AI: The authors have not employed any Generative AI tools.

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Methodological foundations of teaching the basics of artificial intelligence to lyceum students

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Abstract

Integrating artificial intelligence (AI) into secondary education is crucial in preparing students for an AI-driven world. This study develops and validates a methodological framework for implementing AI education in Ukrainian lyceums. Key contributions include an analysis of existing textbooks, a review of international practices, and the creation of a three-part web quest complex combining theoretical and practical learning. Validated through expert review and pilot testing, the framework enhances student engagement and understanding of AI concepts. The paper provides practical guidelines for educators, emphasizing interactive, project-based learning and the need for robust teacher support.

Keywords

artificial intelligence education, teaching methodology, web quest, interactive learning, educational technology, curriculum development

1. Introduction

The rapid development of artificial intelligence (AI) technologies has led to an increasing demand for AI education at various levels, including K-12 education [1, 2, 3]. As AI becomes ubiquitous in everyday life, it is essential to prepare students for the challenges and opportunities presented by this emerging field [4]. Integrating AI education into school curricula can help develop students' computational thinking skills, foster their interest in computer science, and equip them with the knowledge and skills needed to thrive in an AI-driven world [5].

In Ukraine, the National Strategy for the Development of Artificial Intelligence 2020-2030 emphasizes the importance of introducing AI-related disciplines at different levels of education, including secondary schools [6, 7]. However, the implementation of AI education in Ukrainian lyceums (upper secondary schools) faces several challenges, such as the lack of standardized curricula, limited access to educational resources, and insufficient teacher training [8, 9].

This research paper aims to address these challenges by proposing a methodological foundation for teaching the basics of AI to lyceum students in Ukraine. By analyzing existing AI education frameworks, curricula, and best practices from around the world [10, 11, 12], we seek to develop a comprehensive approach that considers the specific needs and context of Ukrainian education. Our goal is to provide guidelines and recommendations for educators, policymakers, and researchers to facilitate the effective integration of AI education in Ukrainian lyceums.

The main objectives of this study are:

1. To review and analyze existing AI education frameworks, curricula, and best practices from around the world.
2. To identify the key competencies and learning outcomes for teaching AI basics to lyceum students.
3. To propose a methodological foundation for AI education in Ukrainian lyceums, considering the specific needs and context of the Ukrainian education system.
4. To provide recommendations for the implementation of AI education in Ukrainian lyceums, including curriculum design, teacher training, and educational resource development.

AREdu 2024: 7th International Workshop on Augmented Reality in Education, May 14, 2024, Kryvyi Rih, Ukraine
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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

CEUR-WS.org/Vol-3918/paper184.pdf

2. Literature review

The integration of artificial intelligence (AI) education in K-12 curricula has gained significant attention in recent years. Researchers and educators have explored various approaches to teaching AI concepts, skills, and applications to students at different levels.

Several AI education frameworks and curricula have been proposed to guide the integration of AI in K-12 education. The AI4K12 Initiative, launched by the Association for the Advancement of Artificial Intelligence (AAAI) and the Computer Science Teachers Association (CSTA), aims to develop national guidelines for teaching AI in K-12 [13]. The initiative has identified five "big ideas" in AI: perception, representation and reasoning, learning, natural interaction, and societal impact [14].

Other researchers have proposed AI education frameworks that emphasize the importance of integrating technical, social, and ethical aspects of AI. Dai et al. [15] developed a collaborative AI curriculum for primary schools in China, considering the specific needs and context of the Chinese education system. Yue Yim [12] proposed an intelligence-based AI literacy framework for primary school education, emphasizing the need for a transdisciplinary approach that encompasses both technological and societal impacts of AI.

Various teaching approaches and strategies have been explored to facilitate AI education in K-12 settings. Unplugged activities, which introduce AI concepts without using computers, have been found to be effective in engaging students and fostering their understanding of AI principles [14]. Game-based learning, such as using Pac-Man to teach AI concepts [16], has also been shown to increase student motivation and engagement.

Project-based learning and hands-on activities have been widely used to teach AI in K-12 classrooms. Sperling and Lickerman [17] integrated AI and machine learning in a software engineering course for high school students, using DrRacket functional programming language to implement AI algorithms. Sinha et al. [2] proposed a hands-on active learning approach to teach AI and machine learning to elementary and middle school students, using AI4K12 big ideas and culturally responsive pedagogy.

Preparing teachers to effectively teach AI in K-12 classrooms is crucial for the successful integration of AI education. Williams et al. [1] developed an AI ethics curriculum for middle school teachers, providing them with content knowledge and an understanding of the ethical issues posed by AI. Lee et al. [18] proposed an innovative professional development model called "AI Book Club" to prepare middle school teachers with AI content knowledge and ethical considerations.

Olari et al. [19] investigated the introduction of AI literacy and data literacy in computer science teacher education, highlighting the need for professional development programs to train teachers in these emerging skills. Kim and Kwon [20] explored the AI competencies of elementary school teachers in South Korea, identifying 22 competencies based on the technological pedagogical content knowledge (TPACK) framework.

Despite the growing interest in AI education, several challenges and opportunities have been identified in the literature. One major challenge is the lack of standardized AI curricula and learning materials, which can hinder the effective implementation of AI education in K-12 settings [8, 9]. Developing age-appropriate and engaging AI learning resources, such as unplugged activities [14] and project-based learning materials [17], can help address this challenge.

Another challenge is the limited AI knowledge and skills among K-12 teachers [20]. Providing effective professional development opportunities, such as the AI Book Club model [18] and the introduction of AI literacy in teacher education [19], can help prepare teachers to confidently teach AI in their classrooms.

The integration of AI education in K-12 curricula also presents opportunities for fostering computational thinking skills [5], promoting diversity and inclusion in computer science education [21], and preparing students for future careers in AI-related fields [4]. Collaborative efforts among researchers, educators, and policymakers are needed to seize these opportunities and address the challenges in AI education.

3. Methodology

To develop a methodological foundation for teaching the basics of artificial intelligence (AI) to lyceum students in Ukraine, we employed a multi-phase research approach. This section describes the research design, data collection, and analysis methods used in each phase of the study. Figure 1 illustrates the structure of the research methodology.

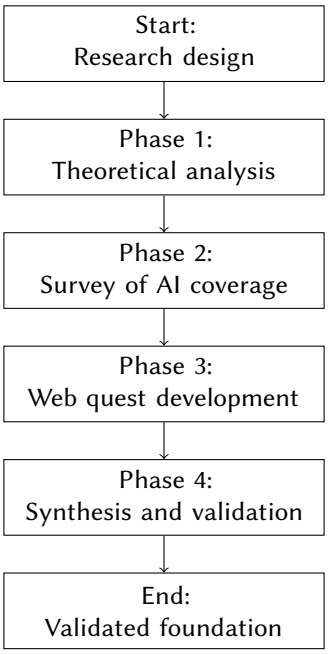


Figure 1: Structure of the research sethodology.

3.1. Phase 1: Theoretical analysis of AI concepts and terminology

The first phase of the study involved a theoretical analysis of key AI concepts and terminology used in high school informatics education. We conducted a comprehensive review of informatics textbooks and educational materials used in Ukrainian lyceums to identify the most common and relevant AI concepts and terms. The analysis focused on the clarity, consistency, and appropriateness of the definitions and explanations provided in these materials.

The data collected in this phase included the AI-related content from 5 informatics textbooks for grades 10-11, as well as supplementary educational materials such as online courses and educational videos. The content was analyzed using qualitative content analysis techniques [22], focusing on the identification of key themes, patterns, and inconsistencies in the presentation of AI concepts and terminology.

3.2. Phase 2: Survey of AI coverage in informatics standards and textbooks

The second phase of the study involved a survey of AI coverage in the current informatics standards and textbooks used in Ukrainian lyceums. We analyzed the national curriculum guidelines for informatics education in grades 10-11, as well as the most widely used informatics textbooks, to determine the extent and depth of AI coverage.

The data collected in this phase included the AI-related content from the national curriculum guidelines and 5 informatics textbooks for grades 10-11. The content was analyzed using a combination of quantitative and qualitative methods. Quantitative analysis involved the calculation of the percentage of pages and chapters dedicated to AI-related topics. Qualitative analysis focused on the identification of the main AI concepts, skills, and applications covered in the materials.

3.3. Phase 3: Development of an educational web quest complex

The third phase of the study involved the development of an educational web quest complex for teaching AI basics to lyceum students. The web quest complex was designed to provide an engaging and interactive learning experience, combining theoretical knowledge with practical activities and real-world applications of AI.

The development process followed the principles of instructional design [23] and the 5E learning cycle model [24]. The web quest complex was created using the Genial.ly platform and consisted of three main components: (1) an introductory module providing an overview of AI concepts and applications, (2) a series of interactive quests focusing on specific AI topics and skills, and (3) a final project allowing students to apply their knowledge and skills to a real-world AI problem.

The effectiveness of the web quest complex was evaluated through a pilot study involving 20 lyceum students from two schools in Kryvyi Rih. The students completed the web quest complex and provided feedback through a survey and semi-structured interviews. The data collected from the pilot study was analyzed using descriptive statistics and thematic analysis [25] to identify the strengths, weaknesses, and areas for improvement of the web quest complex.

3.4. Phase 4: Synthesis and development of the methodological foundation

The final phase of the study involved the synthesis of the findings from the previous phases and the development of a methodological foundation for teaching AI basics to lyceum students in Ukraine. The methodological foundation was designed to provide a comprehensive and coherent approach to AI education, considering the specific needs and context of the Ukrainian education system.

The development process involved the integration of insights from the theoretical analysis, survey of AI coverage, and the evaluation of the web quest complex. The methodological foundation was structured around four main components: (1) key AI concepts and skills to be taught, (2) recommended teaching approaches and strategies, (3) guidelines for curriculum design and resource development, and (4) recommendations for teacher professional development.

The methodological foundation was validated through expert review and feedback from a panel of 5 informatics education experts and 5 experienced informatics teachers. The experts and teachers reviewed the methodological foundation and provided feedback on its clarity, relevance, and feasibility. Their input was used to refine and finalize the methodological foundation.

4. Results and discussion

This section presents the main findings of the study and discusses their implications for the development of a methodological foundation for teaching AI basics to lyceum students in Ukraine.

4.1. Findings from the theoretical analysis of AI concepts and terminology

The theoretical analysis of AI concepts and terminology in informatics textbooks and educational materials revealed several key findings. First, while most materials provided definitions and explanations of basic AI concepts such as machine learning [26], neural networks [27], and natural language processing [28], the depth and clarity of these explanations varied considerably. Some textbooks provided detailed and accessible explanations suitable for high school students, while others used more technical language and assumed prior knowledge of advanced mathematical concepts.

Second, the analysis identified inconsistencies in the use of AI terminology across different textbooks and materials. For example, some materials used the terms “machine learning” and “deep learning” interchangeably, while others made clear distinctions between these concepts. Such inconsistencies may lead to confusion and misconceptions among students.

Third, the analysis highlighted the importance of providing relevant and engaging examples of AI applications to help students understand the real-world impact of these technologies. Materials that

included examples from diverse domains such as healthcare, transportation, and entertainment were found to be more effective in capturing students' interest and promoting deeper understanding.

4.2. Evaluation of current AI coverage in informatics standards and textbooks

The survey of AI coverage in the current informatics standards and textbooks used in Ukrainian lyceums revealed a limited and fragmented approach to AI education. As shown in table 1, the percentage of pages and chapters dedicated to AI-related topics in the analyzed textbooks ranged from 1.5% to 6%, with an average of 3.5%. This indicates that AI is not yet a central focus of informatics education in Ukrainian lyceums.

Table 1
AI coverage in informatics textbooks for grades 10-11

Textbook	Percentage of pages	Percentage of chapters
Textbook by Bondarenko, Lastovetskyi, Pylypchuk, and Shestopalov [29]	2.5%	5%
Textbook by Morze and Barna [30]	1.5%	2.5%
Textbook by Ryvkind, Lysenko, Chernikova, and Shakotko [31]	4%	7.5%
Textbook by Rudenko, Rechych, and Potiienko [32]	3%	5%
Textbook by Rudenko, Rechych, and Potiienko [33]	6%	10%
Average	**3.5%**	**6%**

The qualitative analysis of the AI-related content in the textbooks revealed a focus on basic concepts such as machine learning, neural networks, and expert systems. However, the coverage of these topics was often superficial and lacked practical applications and hands-on activities. Few textbooks included discussions of the ethical and societal implications of AI, which are crucial for developing students' critical thinking skills and preparing them for responsible citizenship in an AI-driven world [34].

4.3. Development and evaluation of the educational web quest complex

The educational web quest complex developed in this study aimed to address the limitations identified in the current AI coverage in informatics education. The web quest complex consisted of three main components: (1) an introductory module providing an overview of AI concepts and applications, (2) a series of interactive quests focusing on specific AI topics and skills, and (3) a final project allowing students to apply their knowledge and skills to a real-world AI problem [35].

The pilot study involving 20 lyceum students revealed positive results in terms of student engagement, knowledge acquisition, and skill development. 85% of the students found the web quest complex to be engaging and motivating, while 90% reported an increased understanding of AI concepts and applications after completing the complex.

The qualitative feedback from the students highlighted the effectiveness of the interactive and project-based learning approach in promoting active learning and fostering problem-solving skills. Students appreciated the opportunity to apply their knowledge to real-world AI problems and develop practical skills such as data analysis and algorithm design.

However, the pilot study also identified areas for improvement in the web quest complex. Some students reported difficulties in understanding certain technical concepts and suggested the inclusion of more visual aids and simpler explanations. Others recommended the addition of more collaborative activities and opportunities for peer learning.

4.4. Proposed methodological foundation for teaching AI basics to lyceum students

Based on the findings from the theoretical analysis, survey of AI coverage, and evaluation of the web quest complex, we propose a methodological foundation for teaching AI basics to lyceum students in Ukraine. The methodological foundation consists of four main components:

1. **Key AI concepts and skills to be taught**
   The foundation emphasizes the importance of covering fundamental AI concepts such as machine learning, neural networks, natural language processing, and computer vision [36]. It also highlights the need to develop students' skills in data analysis, algorithm design, and problem-solving.
2. **Recommended teaching approaches and strategies**
   The foundation recommends the use of interactive and project-based learning approaches to promote active learning and engage students in the learning process [37]. It also emphasizes the importance of incorporating real-world examples and applications of AI to help students understand the relevance and impact of these technologies.
3. **Guidelines for curriculum design and resource development**
   The foundation provides guidelines for designing an AI curriculum that is aligned with the national informatics standards and integrates AI concepts and skills throughout the learning process. It also offers recommendations for developing engaging and accessible learning resources, such as interactive web quests, simulations, and hands-on activities [38].
4. **Recommendations for teacher professional development**
   The foundation recognizes the crucial role of teachers in implementing effective AI education and provides recommendations for teacher professional development [39]. These include the provision of training programs on AI concepts and pedagogical strategies, the establishment of teacher networks and communities of practice, and the development of online resources and support materials for teachers.

The proposed methodological foundation aims to provide a comprehensive and coherent approach to AI education in Ukrainian lyceums, addressing the limitations identified in the current informatics education and leveraging the insights gained from the development and evaluation of the web quest complex.

4.5. Implications and future directions

The findings of this study have important implications for the integration of AI education in Ukrainian lyceums. First, they highlight the need for a more systematic and comprehensive approach to AI education, one that goes beyond the superficial coverage of basic concepts and encompasses the development of practical skills, critical thinking, and ethical reasoning.

Second, the study emphasizes the importance of engaging and interactive learning approaches, such as project-based learning and web quests, in promoting student motivation and knowledge acquisition. This calls for a shift from traditional lecture-based teaching to more student-centered and active learning strategies.

Third, the study underscores the crucial role of teacher professional development in implementing effective AI education. Providing teachers with the necessary knowledge, skills, and resources to teach AI is essential for ensuring the success and sustainability of AI education initiatives.

Future research should focus on the large-scale implementation and evaluation of the proposed methodological foundation in Ukrainian lyceums. This could involve the development of a national AI curriculum, the creation of a repository of AI learning resources, and the establishment of a network of AI education experts and practitioners. Additionally, research could explore the long-term impact of AI education on students' academic and career outcomes, as well as on their attitudes towards AI and its societal implications.

5. Conclusions

This research paper aimed to develop a methodological foundation for teaching the basics of artificial intelligence (AI) to lyceum students in Ukraine. Through a multi-phase research approach, we conducted a theoretical analysis of AI concepts and terminology, surveyed the current state of AI coverage in informatics standards and textbooks, developed and evaluated an educational web quest complex,

and synthesized the findings to propose a comprehensive and coherent approach to AI education in Ukrainian lyceums.

The theoretical analysis revealed inconsistencies and limitations in the presentation of AI concepts and terminology in current informatics textbooks and educational materials. The survey of AI coverage in informatics standards and textbooks indicated a limited and fragmented approach to AI education, with an average of only 3.5% of pages and 6% of chapters dedicated to AI-related topics. The development and evaluation of the educational web quest complex demonstrated the effectiveness of interactive and project-based learning approaches in promoting student engagement, knowledge acquisition, and skill development in AI education.

Based on these findings, we proposed a methodological foundation for teaching AI basics to lyceum students in Ukraine. The foundation consists of four main components: (1) key AI concepts and skills to be taught, (2) recommended teaching approaches and strategies, (3) guidelines for curriculum design and resource development, and (4) recommendations for teacher professional development. The foundation emphasizes the importance of covering fundamental AI concepts, developing practical skills, incorporating real-world examples and applications, and promoting active learning through interactive and project-based approaches.

The implementation of the proposed methodological foundation has the potential to address the limitations identified in the current AI education landscape in Ukrainian lyceums and to prepare students for the challenges and opportunities of an AI-driven world. However, the successful integration of AI education in Ukrainian lyceums will require a concerted effort from policymakers, educators, and researchers to develop a national AI curriculum, create engaging and accessible learning resources, and provide comprehensive teacher professional development opportunities.

Future research should focus on the large-scale implementation and evaluation of the proposed methodological foundation in Ukrainian lyceums, as well as on the long-term impact of AI education on students' academic and career outcomes. Additionally, research could explore the potential of AI technologies to enhance and personalize the learning experience, such as through adaptive learning systems [40] and intelligent tutoring platforms [41].

Declaration on Generative AI: During the preparation of this work, the authors used Claude 3 Opus in order to: Text Translation, Abstract drafting, Content enhancement. After using this service, the authors reviewed and edited the content as needed and takes full responsibility for the publication's content.

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The use of ICT by teachers for the development of students' critical thinking in the context of sustainable development in Ukraine

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Abstract

The globalised world and modern society require teachers to use new digital technologies and at the same time set the task of developing critical thinking of their students. Critical thinking is one of the conditions and components of education for the sustainable development of society. The purpose of this article is to examine how teachers in Ukraine use ICT to foster students' critical thinking in the context of sustainable development. The analysis and interpretation of quantitative data were carried out using the methods of descriptive and mathematical statistics, following general scientific approaches. The most effective forms of education today are distance and mixed learning. One of the important aims and at the same time teaching method is the development of students' critical thinking. Results and practical significance. This article discusses the selection of ICT resources and tools for developing critical thinking skills. It also examines how teachers view the use of digital tools in their professional development and provides information on how Ukrainian teachers use these tools in wartime conditions. However, further research is needed to monitor how teachers use ICT tools to promote critical thinking.

Keywords

critical thinking, sustainable development, digital tools in education, distance learning, blended learning, teacher professional development, wartime education, 21st-century skills

CEUR-WS.org/Vol-3918/paper203.pdf

1. Introduction

The development of critical thinking is an important task for Ukrainian teachers today. Circumstances related to military actions on the territory of Ukraine actualized the need to responsibly and critically use digital tools and ICT for education because a large part of educational activities is carried out remotely. According to the Ministry of Education and Science of Ukraine, 12,926 schools operate in Ukraine, 955 school children study face-to-face, 4,363 – remotely, and 4,608 – in a mixed form. More than 510,000 schoolchildren and more than 12,000 teachers continue to stay abroad [1]. This made it necessary for teachers to select and use digital resources that will contribute to the formation of students' responsible and critical behaviour and will form citizenship and democratic values in the framework of learning school disciplines. Also, the European vector of development and restoration of educational losses, both after the COVID-19 quarantine [2, 3] and in wartime, directs teachers to the formation of European and world values of humanity, in particular those related to the preservation of life and observance of human rights, preservation of the environment, sustainable development of society. The formation of critical thinking is carried out by teachers both within the framework of compulsory educational disciplines and within the framework of extracurricular activities and other activities. The educational practices of using online resources and various approaches to their use considered in this work allow forming the logical and critical thinking of students. The identification of several tools and teachers' attitudes to the use of digital tools forms a modern picture of teachers' perception of the educational process with the help of ICT.

AREdu 2024: 7th International Workshop on Augmented Reality in Education, May 14, 2024, Kryvyi Rih, Ukraine

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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

2. Research methods

The purpose of this article is to examine how teachers in Ukraine use ICT to foster students' critical thinking in the context of sustainable development.

The research tasks:

1. Identifying the public opinion of teachers and other school professionals regarding the problems and readiness of teachers to use digital technologies during the war period.
2. To single out recommendations for the teacher training system regarding the use of digital tools and means for the development of critical thinking.

In the research process, the results of the monitoring conducted by the Institute of Digitalization of Education of the National Academy of Sciences of Ukraine were used, which was aimed at identifying the public opinion of teachers and other school professionals regarding the problems and readiness of teachers to use digital technologies during the war period. The results of the teachers' survey presented in the article are based on the questions formulated according to the "European DigComp for Citizens" approach proposed by Clifford et al. [4]. The analysis and interpretation of quantitative data were carried out using the methods of descriptive and mathematical statistics, following general scientific approaches. The authors used the methods of descriptive analysis of the approaches of different authors to the use of ICT for the formation of students' critical thinking, and description of the experience of using ICT in other countries (Czech Republic, USA, Germany, etc.). The conducted analysis made it possible to single out recommendations for the teacher training system regarding the use of digital tools and means for the development of critical thinking.

3. Literature review

Critical thinking is defined as the process and practice of examining evidence to arrive at informed decisions and beliefs. This process involves examining the evidence and examining the problem from different perspectives. This approach is common in the Western tradition, dating back to famous figures from Socrates to R. Descartes and J. Dewey [5]. The theory of critical thinking was developed in modern cognitive psychology, which is based on a wide experimental and research base. The most famous representatives of cognitive psychology are G. Miller, J. Bruner, U. Neisser, A. Bandura, N. Chomsky, S. Carey, R. Gelman and others who have made significant contributions to the field of cognitive psychology [6].

Since the development of critical thinking is a subject of cognitive psychology, which is projected onto the pedagogical sphere, it is worth paying attention to the positions expressed by modern educators. Educators pay attention to the ways and means by which students' critical thinking can be developed. Castells et al. consider education and the development of critical thinking that can contribute to social and political changes in the context of ecology, media, and individual liberty in their pursuit of new ideas that can inform the fundamental practice of education and promote a more humane civil society [7]. Rashid proposes ways in which critical thinking can be developed in education: encourage students to ask questions; teach students to evaluate information; teach students to analyse information; encourage students to think creatively; provide opportunities for reflection; and teach students to communicate effectively [8]. Terno, the Ukrainian researcher, claims that critical thinking is thinking that is conscious, independent, reflective, purposeful, grounded, controlled, and self-organized and offers his vision of the formation of students' critical thinking in the process of studying history [9]. The technology proposed by him is based on programmed and developmental learning, which, in his opinion, ensures students' assimilation of historical concepts in the system at the theoretical level of generalization, as well as increases the systematicity, strength and depth of knowledge. Cole, DeLecce and Pisano believe that there are a variety of ways to parse the skills involved in critical thinking. One way to formulate the skills involved includes the following seven: emotional skills, inference, observation, questioning, imagination, consulting, and judging [5]. Semerikov et al. authors state the importance of developing design methods for immersive e-learning resources, educational, scientific, informational, reference

materials and tools used in an immersive environment, reproduced by immersive technical tools, and necessary for effective organization of the educational process [10]. At the same time, investigations in different countries show, that that even teachers with sufficient technology skills are not comfortable or prepared to integrate technology into the classroom. Mynaříková and Novotný state that even frequent ICT users are often not sure about how to implement digital instruments into their specific subjects. The authors point out that the missing link might be the absence of structured, continuous training in the use of ICT in teaching [11].

Based on the above-mentioned provisions, it is necessary to focus on important positions regarding the impact of the use of ICT by teachers on the development of students' critical thinking. At the same time, it is worth identifying those aspects related to the transformation of educational activities in the context of sustainable development. The role and impact of the use of ICT and digital tools by teachers in the process of the development of student's critical thinking in the context of sustainable development is closely related to the quality of education, in particular:

- ICTs have become indispensable tools to deal with different societal needs through a transformation of educational practices;
- ICTs contribute to inclusive education and the creation of learning opportunities;
- digital tools help reduce social and economic inequalities that may exist in society, as well as favour the inclusion of people in education, provided that there is equality of opportunity [12].

However, Plaza-de la Hoz states that ICT should not be used merely as a support resource or as something exceptional, but rather, should be carried out during pedagogical practices aimed at creating a more sustainable model [13]. In ICT-mediated classroom students, when they search the World Wide Web, their analytical thinking skills can be developed because students get the opportunity to gain access to information which provides them with many different perspectives, but these must be used with other tools [14].

Digitisation provides access to an integrated big data network with potential benefits for society. The development of digital technologies can create unique opportunities for strategic solutions to problems related to the UN Sustainable Development Goals [15]. The study by ElMassah and Mohieldin [16] examines how digital transformation can impact localisation and the achievement of the Sustainable Development Goals (SDGs). Despite the positive effects and variety of applications of digital technologies [17], issues such as data scarcity, high power consumption of computing resources, ethical concerns, privacy, ownership, and security issues stand in the way of achieving the 17 SDGs. Hoosain, Paul and Ramakrishna [18] explores, through implementation case studies, how digital technologies are being used across sectors to enable understanding and addressing the framework agreed upon in 2015 by 193 countries, i.e., the 17 UN Sustainable Development Goals.

4. Research results

Based on the work by Sachs et al. [19] six transformations of the Sustainable Development Goals can be presented as modular building blocks for achieving them: education, gender and inequality; health, welfare and demography; decarbonization of energy and sustainable industry; sustainable food, land, water and oceans; sustainable cities and communities; and the digital revolution for sustainable development.

The first block includes three sets of interventions to promote education and gender equality and reduce inequality. First, countries must expand and transform education systems. Early childhood development accelerates children's cognitive and emotional development with lasting effects into adulthood but is underinvested in many countries, including high-income countries. General quality primary and secondary education is the basis of education systems. This requires improved teacher training, curriculum development, and ongoing assessment of learning outcomes. Vocational training, school-to-work programs and higher education are underdeveloped in most countries, even though they improve school-to-work transitions, increase lifetime earnings and reduce inequality. Finally,

to promote economic growth, most countries need to stimulate innovation and ensure the spread of research and development. The introduction of new technologies can be accelerated through higher education; national science funding mechanisms and scientific advisory bodies; innovation hubs [19].

Artificial intelligence [20] and other digital technologies require a comprehensive set of regulatory standards, physical infrastructure and digital systems to take advantage of the digital revolution to achieve the Sustainable Development Goals.

The implementation of this block consists of several sets of interventions. First, universal access to high-quality, low-cost mobile broadband. Second, measures to promote digital inclusion, skills, privacy and universal identity. Also, it is necessary to strengthen state institutions to manage and shape digital innovations in the direction of sustainable development. Therefore, it can be argued that the development of students' critical thinking is directly related to the implementation of the following sustainable development goals (presented in the form of blocks): education, gender and inequality; digital revolution for sustainable development.

Based on the studied sources and scientific investigations, the main stages of the formation of critical thinking were clarified in the research process. The stages of formation of students' critical thinking include the following sequence of actions: asking questions, perceiving new information, self-analysis, and communication.

The most successful techniques for the formation of critical thinking are: brainstorming, clusters, working in pairs, associations, etc. Using ICT capabilities, the teacher can involve students in creating blogs, web applications, presentations, playcasts, exhibitions, electronic libraries, etc. These forms of organizing work with the class can be used in the process of mastering any educational subject. For their successful use, it is necessary to rethink the content of the educational material. The teacher should approach thematic planning from a different point of view. New and interesting forms of working with students are the use of virtual and augmented reality (VR, AR) [21], and artificial intelligence (AI) [22]. It is difficult for teachers to do this when the mixed form of education or distance learning prevails [23].

Considering these factors, it will be more appropriate to form critical thinking with the use of digital technologies, as they are an integral part of conducting distance or blended learning. Digital technologies in the educational process contribute to the development of student independence, adaptation, increased student motivation, individualization, and comfort.

In the context of the specified stages of the formation of students' critical thinking with the use of digital tools, it is worth paying attention to the relationships and interactions between the teacher and students (figure 1).

Figure 1 highlights the following main positions:

1. The sequence of the teacher's actions for the development of students' critical thinking (stages).
2. Forms, methods and techniques of using ICT to work with students.
3. Digital means and tools allow the teacher to apply new forms of learning for the development of critical thinking.

All the mentioned positions are interconnected and allow us to follow the relationships and interactions of the teacher and students in the learning process. According to Rashid, it should be agreed that among the teacher's tasks are the following: encourage students to ask questions; teach students to evaluate information; teach students to analyse information; encourage students to think creatively; provide opportunities for reflection; teach students to communicate effectively [8].

It was found that critical thinking develops in the process of creating new content by students. Thanks to the creation of cartoons, web applications, blogs, animated videos, scrapbooks, presentations, libraries, exhibitions, and participation in competitions, students acquire new information and master digital technologies. Working on a joint educational project encourages participation in creative competitions. Learning material becomes more interesting because it is studied in more detail by a group of students with common interests. In this way, students can develop critical thinking.

For example, a teacher in a computer science class may not just teach material on the subject of information security, which is the subject of study in the 9^{th} grade (Basics of Information Security).

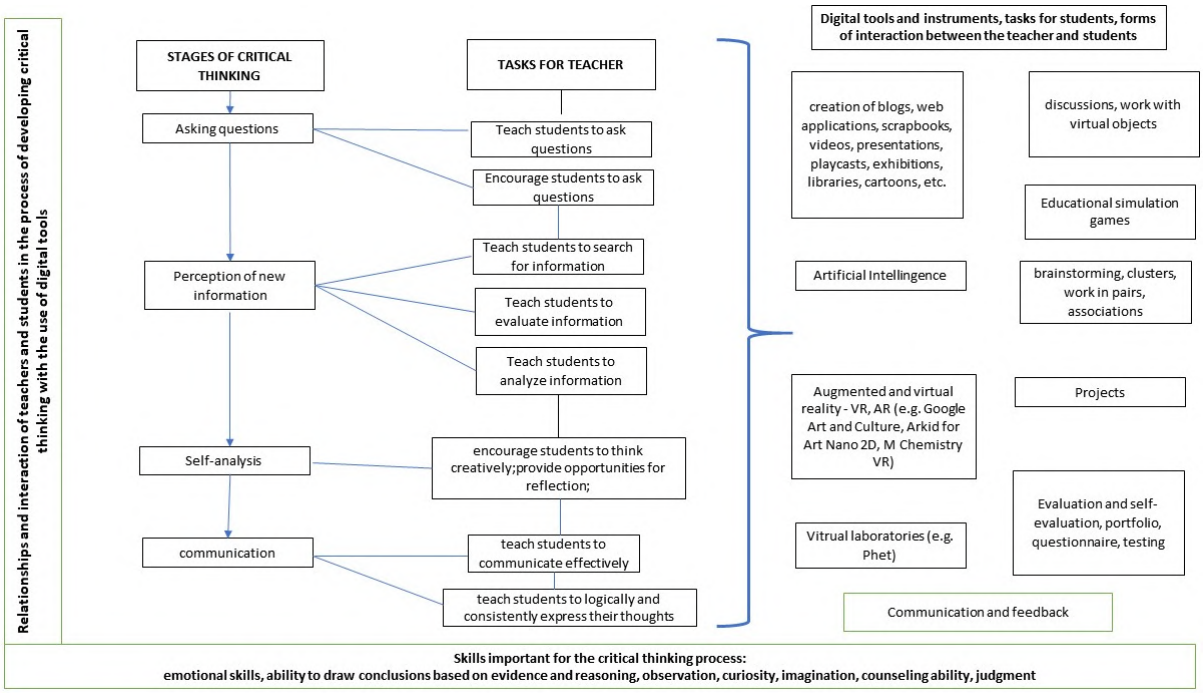


Figure 1: Relationships and interaction of teachers and students in the process of developing critical thinking with the use of digital tools.

Such a lesson can be built in such a way that it is an active activity of students, that it is an active discussion. It is important to stimulate discussion and teach students to express their point of view, to try to listen to others and to correctly treat the opposite point of view that does not coincide with their own. Together, in groups or micro-groups into which the class is divided, you should come to a common conclusion, or refute false theses, and false narratives, arguing it with concrete facts. Today, teachers are offered developed online materials that can be used to form critical thinking in an informatics lesson: the lesson is the game "Information Security" for the 9^{th} grade [24]; online tests "Basics of information security" [25]; lesson notes and visual materials [26].

Artificial intelligence is a unique tool for the formation and development of critical thinking. How can a teacher use this in teaching? There are certain patterns of requests for AI services that students should be taught how to use correctly. It should be explained that from the way the request is formulated, it is possible to receive both completely reliable information and distorted or false information. AI does not always give a hundred per cent guarantee of the correct answer. Therefore, the teacher should explain to the students that they should be critical of the generation of answers by artificial intelligence. Among the practical tasks that stimulate students' critical thinking, one can include, for example, questions related to how to recognize fake information. At the same time, the teacher encourages students to use digital resources. So, a computer science teacher can give examples of some services that store an archive of sites (for example, the Wayback Machine). If a page on a specific site has been deleted, this service helps to find the deleted page. This is useful if a particular news story has been published and then deleted. In this way, you can track the process of creating fake information. Google Images can be used to find the source of an image. This is useful to investigate, for example, when manipulating fake images. Students should be taught to be critical of anything they read on the Internet. It can be argued that the Google Image service is a kind of artificial intelligence service.

Critical thinking encourages students to respond to issues related to their position in society and community, in particular, democratic citizenship and human rights, sometimes in opposition to expectations of support and answers from teachers. This is important, because critical thinking helps learners to independently reflect on what are the signs of democratic citizenship, and also contributes to personal achievements and the ability to take responsibility for their actions and joint decisions

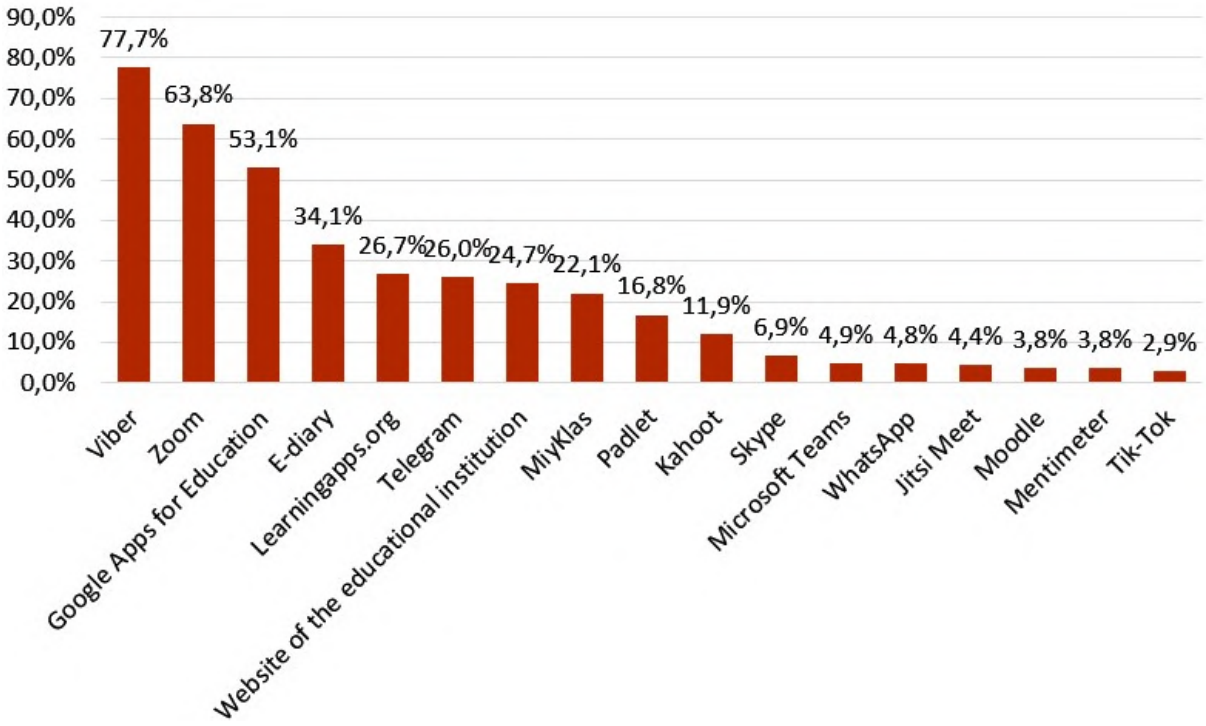


Figure 2: Digital instruments used by teachers for conducting online classes in 2023 [31].

[27]. This is important for students' understanding of social values, personal role in preserving the environment, development of impartial judgment skills and logical thinking in general.

Discussions, working in pairs, and brainstorming are unique incentives for forming the skills to draw conclusions and conduct their research, express opinions and defend students' positions, as well as generate ideas alone or in a group. Cowling states that these methods can be applied to teaching Mathematics, Science, Reading/Language Arts, and Social studies [28].

To find out the state of ICT use by teachers today, it is necessary to turn to current research that shows which tools and tools are most popular among teachers. In 2023, the Institute for Digitalization of Education of the National Academy of Educational Sciences of Ukraine conducted an all-Ukrainian survey "Readiness and needs of teachers regarding the use of digital tools and ICT in conditions of war: 2023". Regarding the type of Information and Communication Technology (ICT) used by teachers it was found that only a third of schools in Ukraine work full-time, at other institutions and, accordingly, teachers organize distance and mixed learning for their students [29]. The situation is further complicated by the fact that some of the institutions are located in the occupied territories, some of the educational infrastructure has been lost, and a certain number of teachers and children have left their places of permanent residence, that is, they are internally displaced persons (IDPs) or refugees. In the course of an all-Ukrainian survey conducted in 2023, it was found out that the following digital tools are mostly used by teachers to organize distance learning, as can be seen in figure 2: Viber – 78.4%; Zoom – 65.4%; Google Apps for Education – 53.1% (only 20.2% of respondents used this tool last year). Respondents use an electronic diary twice as much – 34.1% in 2023 compared to 15.4% in 2022. The percentage of Telegram users also doubled – 26% compared to 13.3% in 2022. Among other tools, respondents indicated the following: Learningapps.org – 26.7%; the website of the educational institution – 24.7%; MiiKlas – 22.1%; Padlet – 16.8%; Kahoot – 11.9%; Skype – 6.9%; Microsoft Teams – 4.9%; WhatsApp – 4.8%; JitsiMeet – 4.4%; Moodle – 3.8%; Mentimer – 3.8%. Less than 1% scored tools such as Twitter, Cisco Webex, Wordwall, Liveworksheets, Discord etc. [30].

Special attention during the survey of teachers was paid to their professional development. After all, teachers are changing traditional education in a variety of ways by taking advantage of technology, including increasing attention to distance education and its many uses in their classrooms and using it

as a way to address the inequality of participation and the digital divide in society. Therefore, during the survey, teachers were asked about the ways that they receive information about training on the use of digital tools and instruments in the classroom. Teachers were also asked which organisations primarily provide professional development for them (figure 3).

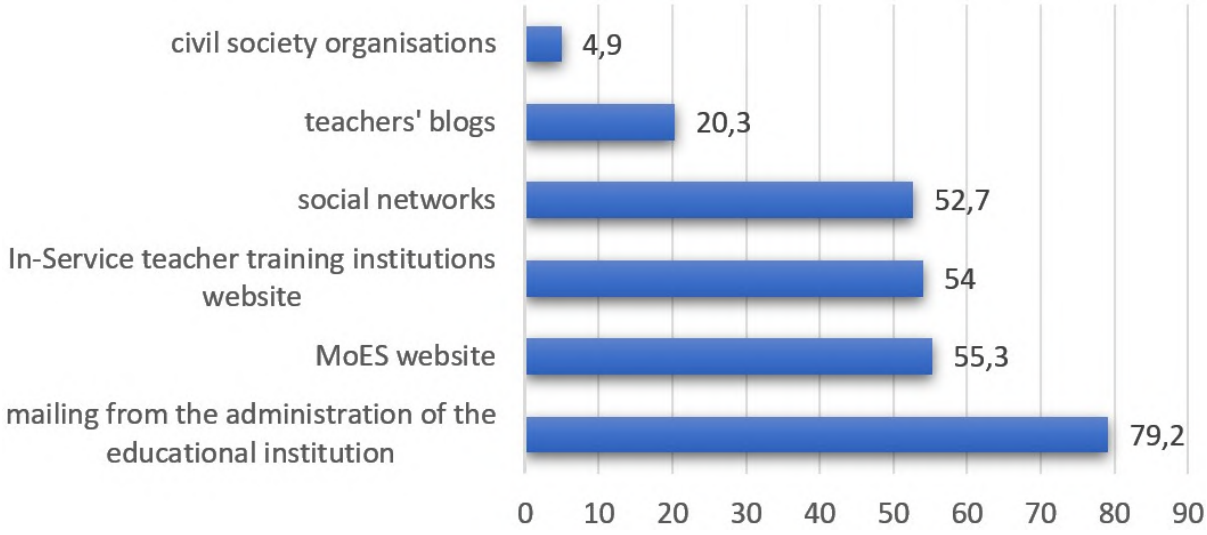


Figure 3: Teachers' answers on where they search for information about training on the ICT use for distance teaching (in %) [31].

First of all, Ukrainian teachers receive the main information from e-mails sent by the administration of their educational institutions (79.2%). 55.3% of teachers receive such information from the website of the Ministry of Education and Science of Ukraine, and only 54% receive information from professional development institutions (figure 3). This indicates the need to introduce more programs to study the possibilities of using ICT during lessons in such institutions and the existence of certain gaps today. A positive trend is that social networks have become a certain factor for sharing experiences regarding the use of digital tools by teachers, and this is evidenced by the results of the survey, which showed that 52.7% of teachers actively communicate on these topics.

5. Discussion

To compare the results we obtained during the teacher survey, we can refer to the study described by Lorente, Arrabal and Pulido-Montes [32]. The authors, based on the results of the Global Education Monitoring Report 2023, conduct a comparative study of the infrastructure, resources and real competencies of the teaching staff for the development of distance learning. Thus, the percentage of teachers with effective professional resources to learn to use digital devices was 75–95% in most countries in Central and East Asia, as well as in the United States, Canada, Norway, Denmark, Estonia, Lithuania, Austria, the Czech Republic, Slovakia, Bulgaria and the United Arab Emirates. The rest of the European countries, along with Chile, Panama, French Guiana and the Dominican Republic, achieved figures in the range of 55–75%. Countries below this range included Germany, Portugal, Ireland and the rest of the Latin American and Caribbean region, showing values between 35–55%.

As noted in the "Global Education Monitoring Report 2023: Technology in Education: a Tool on Whose Terms?" technology influences teacher training and is used to create flexible learning environments, engage teachers in collaborative learning, facilitate coaching and mentoring, develop reflective practice, and improve thematic or pedagogical knowledge. Distance education programs contribute to the improvement of the level of teacher training: virtual communities appear, mainly based on social networks, for the exchange of information and resources. About 80% of Caribbean teachers surveyed were in professional WhatsApp groups and 44% used instant messaging to collaborate at least once a week [33].

The results of the teachers' survey conducted in Ukraine also revealed several problems that arose during the war, including power outages and the lack of Internet access, students' unstable access to computers and the lack of necessary tools, psychological problems and other issues that need to be solved. The difficult conditions in which schools and teachers find themselves affect the full-fledged educational process. It is these conditions that encourage society and teachers to develop the critical thinking of their students, to develop the ability to independently study and research processes, defend their own opinions and develop civic qualities. It became obvious that the state and educational authorities should provide comprehensive support to teachers and students, implement policies aimed at sustainable development of education, and provide quality educational services.

6. Conclusions

The Sustainable Development Goals require profound transformations in every country, which will require additional actions by governments, civil society, science and business. For convenience, all the Sustainable Development Goals have been grouped into six blocks for achieving them: education, gender and inequality; health, welfare and demography; decarbonization of energy and sustainable industry; sustainable food, land, water and oceans; sustainable cities and communities; and the digital revolution for sustainable development. This study partially solves the problems of blocks: education, gender and inequality; and the digital revolution for sustainable development. The use of digital tools by teachers and the development of critical thinking in students is related to these two blocks.

The issue of supporting teachers in the use of digital means and tools for conducting lessons is extremely relevant. This is evidenced by the research results shown. Having analyzed the problem of the use of ICT by teachers to ensure the sustainability of quality education and the development of critical thinking, it is necessary to single out certain considerations and suggestions that may be useful at the current stage. The Ukrainian school entered the second phase of the implementation of the "New Ukrainian School" reform. This means that today the content of school programs is being updated and the transition to new textbooks, new online learning resources and new, active learning methods is taking place. Among the priorities of the reform is the development of soft skills, including critical thinking, as the main component of such skills. The national report on the results of the international study PISA-2022 showed disappointing results. For example, there are differences between schools observed in Ukraine, reflecting the gap between educational institutions located in large cities and towns and rural areas, as well as between different types of educational institutions; in many regions, educational opportunities remain unevenly distributed and depend on where students live. The educational environment and resources of educational institutions in urban and rural areas differ, which affects the success of students who live in different types of settlements and study in educational institutions with different educational programs [34].

Based on the mentioned above, attention should be paid to the opportunities of digital tools for learning. All teachers should receive appropriate training in the use of appropriate ICT. Professional development programs should include courses on training teachers of various subjects to use digital tools, teachers should be consulted at their request, individually, according to the needs of the school. Some work should be done with parents of students so that parents provide support for their children to access distance learning, and motivate them in the difficult conditions of war in Ukraine. Psychological support for teachers and students should be provided continuously, remotely and informally by various educational institutions, regardless of the level and location of the school. For this, tutors should be trained to work on the specified issues at the school level.

Critical thinking as a component of soft skills should be included in all teacher professional development programs, taking into account mandatory training in the forms and methods of using digital means and tools for the formation of students' critical thinking. The issue of monitoring the practice of teachers to form critical thinking using ICT tools, the creation of online networks for sharing positive experiences, the development of special professional development programs on these issues and the involvement of teachers require further research.

Declaration on Generative AI: The authors have not employed any Generative AI tools.

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Using intelligent agent-managers to build personal learning environments in the e-learning system

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Abstract

The article focuses on the issues of developing the structure of a multi-agent environment for e-learning systems and proposes a computer technology to ensure student activities in e-learning modular systems. The relevance of the research topic is due to the low level of modern e-learning systems adaptation to the individual characteristics of the student, the lack of ability to predict learning outcomes. The technology enables to take into consideration the factors affecting the students' learning outcomes and to form an individual trajectory of the learning session from a holistic perspective.

Keywords

e-learning, distance learning, personal learning environment, intelligent agent-manager

1. Introduction

In modern e-learning systems, it is important to deliver dynamic learning materials, as well as manage the training course system in a prompt manner, that is, the e-learning system should provide the user with optimal content and encourage working in groups. An intelligent agent-manager should refer students to the most relevant community or knowledge communities, examining the materials that other community members look through, and connect students and experts [1].

The introduction of e-learning systems has also accelerated the evolution and the learning process in higher education institutions, given the constraints of non-adaptive systems, resulting in the introduction of new open intelligent systems that are used simultaneously with web technology. This is critical to the e-learning technology being implemented across the globe [2].

Tutor agents and support systems play an important role in improving learning outcomes, as they provide continuous assistance to students in the learning process. Some of the existing learning support systems are used at the organizational level and integrated into the current organizational structure of the educational institution [3]. Such learning support systems enable to connect existing users, share important information, improve the training of technical personnel, and improve organizational processes, making them more efficient. However, most existing learning support systems operate with a small number of functions that do not contribute to the development of the e-learning environment required for groups and students to achieve their learning goals in the corresponding fields [4].

The main disadvantage of present-day learning management systems is the failure to provide students with assistance in the distance learning process, and therefore they are unable to replace the physical

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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

CEUR-WS.org/Vol-3918/paper296.pdf

presence of a tutor, who generates the students' work progress. In fact, it is proposed to integrate for each student a metacognitive agent that would ensure metacognition assistance and reveal defects in the learning process and strategies. The goal is to encourage students to improve their learning outcomes measured against the learning goals and refine the learning method. The results show that there are relationships between different metacognitive attributes and student's academic excellence, that is, there is a dependence of metacognitive influence on learning outcomes, reflecting the degree of student's understanding of a particular training unit [5]. There are certain difficulties associated with a large number of micro-modules and the need to form a learning trajectory tailored to the student's needs. One of the ways to overcome these obstacles may be the use of adaptation technology [6].

Thus, the state of elaboration of this problem and current trends in the development of management systems for educational environments for e-learning are indicative of its theoretical and practical significance, and determine the urgency of the chosen theme. The goal of the research is to develop a functional architecture that supports the above goals of e-learning using mobile agent technology.

The introduction of multi-agent systems is one of the most promising areas for building virtual educational environments for distance education systems. The goal of this article is the possibility of illustrating the advantages of using intelligent agents to optimize the location and configuration of appropriate resources for distance learning courses and organizing collective collaboration in the e-learning environment.

The main objectives of the research are to develop the structure of the training service based on the use of a personal learning environment and intelligent agent-managers, which may be used to ensure individual learning. It uses a set of agents that may personalize learning based on previous requests from students (or groups of students), and improve learning and collaboration based on previous knowledge and learning styles.

2. Results

As of today, the SCORM (Shareable Content Object Reference Model) standard that is a standard for sharing learning materials based on the IEEE 1484.12.1 standard model [7] has been developed, and is currently being used. SCORM has been developed to ensure the multiple use of learning materials, support for and adaptation of training courses, introduction of information of individual training materials into training courses or disciplines in accordance with individual user requests. In June 2006, the United States Department of Defense established that all developments in the field of e-learning should meet the SCORM requirements. A promising direction for e-learning standardization has become the successor of SCORM – Tin Can API model [8], which enables to consider the types of learning activities that are not available in SCORM: mobile learning, simulations, informal learning, games; tracks events without using the Internet, and has a reliable system for maintaining the required level of security and user authentication.

When creating complicated and distributed systems, multi-agent systems (MAS) can offer a variety of solutions, especially in the field of distance learning. The combining of agent technology with other methods such as the Educational Data Mining (EDM) and Case-Based Reasoning (CBR), which in turn are based on cloud technology, is important in taking the learning process to the next level. The three-level multi-agent management architecture for distance learning in the e-learning system, which contains the following set of intelligent agents, is proposed to meet the above functional requirements (figure 1):

- Tutor Agent is a set of tools for creating rules that enable tutors to adapt the selection of learning material, define appropriate search terms for finding learning materials based on certain learning styles, and to communicate with other agents for collaboration and establish interaction between tutors and students in a distance learning system.
- Lesson Planning Agent is designed to collect information and complicated reasoning required for defining and developing a curriculum [9].

- Learner Agents are required to organize the effective interaction of students with the e-learning environment, and enable to unite various learning resources into a single whole and constantly monitor learning outcomes.
- Personalization Agents are responsible for customizing training materials based on the preferred learning style of each individual student or workgroup [10].

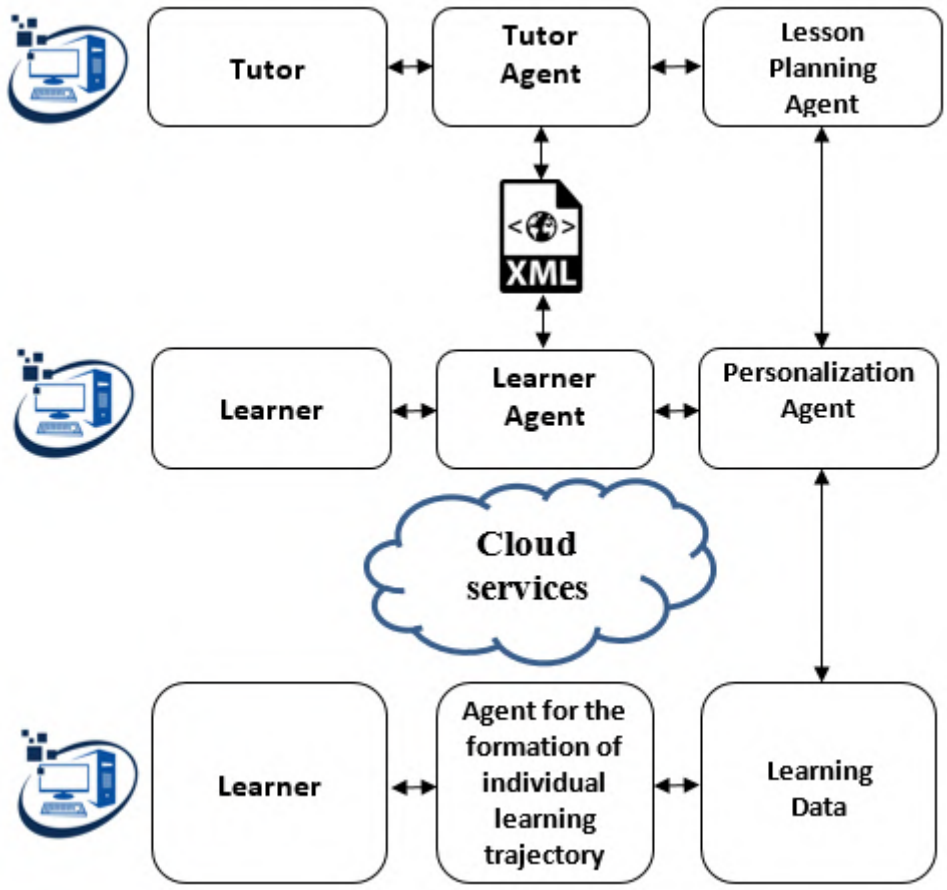


Figure 1: Architecture of distance learning multi-agent management in e-learning systems.

The greatest interest for implementing LMS is represented by learning agents, which in some literature are also referred to as autonomous intelligent agents that determines their independence and ability to learn. Figure 2 shows the flow of work of an agent-manager as part of LMS, which meets the following requirements: to work in real-time mode; learn based on a large amount of data; analyze oneself in terms of behavior, mistakes and success; contain a database of examples with the possibility of replenishing it, as well as learn and develop in the process of interaction with the environment [11, 12, 13].

The objective of formalized description of modular e-learning systems to ensure the ergonomic quality of human-machine interaction has been solved. As a result, a complex of component and morphological models, which is the basis for the formation of information support to adaptive e-learning as the "man – technology – environment" classical systems and contribute to the search for ergonomic reserves of computer human dialogue interaction has been obtained [14] (figure 1). The set of models is given by the scheme shown in figure 3, and is described by structural formula (1). The description of the designations accepted in the formula is given in figure 3.

$$\begin{aligned} MMS =< & EE, OT, PO, MODUL, KPKT, SPF, SVP, SVFS, SGOT, SMT, \\ & EREM, KvPEE, KvNpEE, KvOT, KvPKT, KvPT, MKvHEE, \\ & MFSEE, MKvMODUL, MKvMOD, ProgPPR, MDV, MUT > \end{aligned} \quad (1)$$

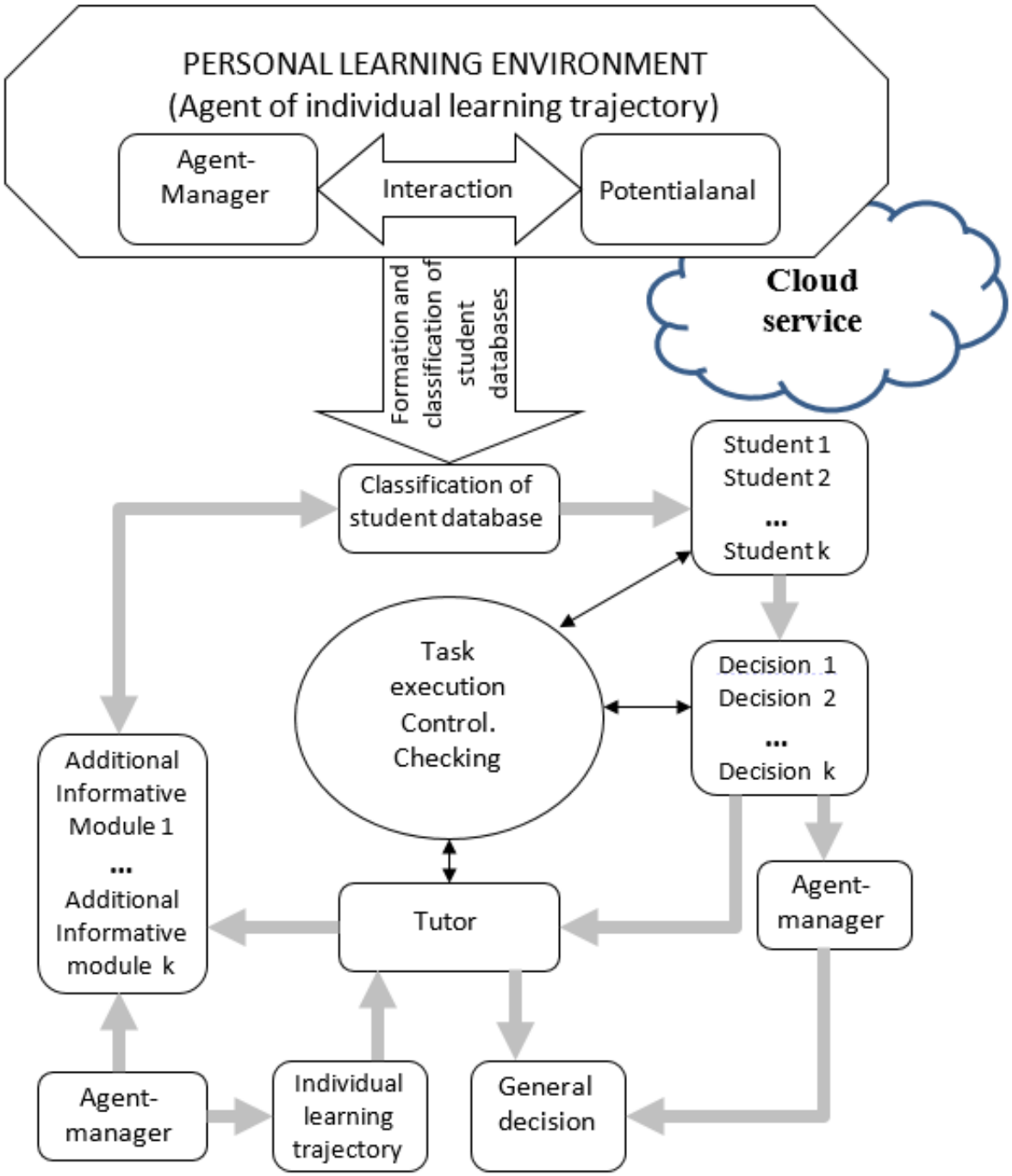


Figure 2: Flow of work of an agent-manager as part of LMS.

Here are the structures of some models.

Component model of elements of module. It describes the structure of educational module.

$$MODUL =< [idmod_i, [PO_k, [tema_{kj}]|j \in [1,2,...,KT_k]|k \in [1,2,...,KPO], [PMod_{il}, [Srmod_{iln}]| \\ |n \in [1,2,...,KSr_{il}], [Sdmodilk]|z \in [1,2,...,KSd_{il}], Pruk_{il}]|l \in [1,2,...,KPmod_i] > \quad (2)$$

where $idmod_i$ is the identification of the i-th module;

PO_k is the k-th subject area;

$tema_{kj}$ is the j-th theme of the k-th subject area;

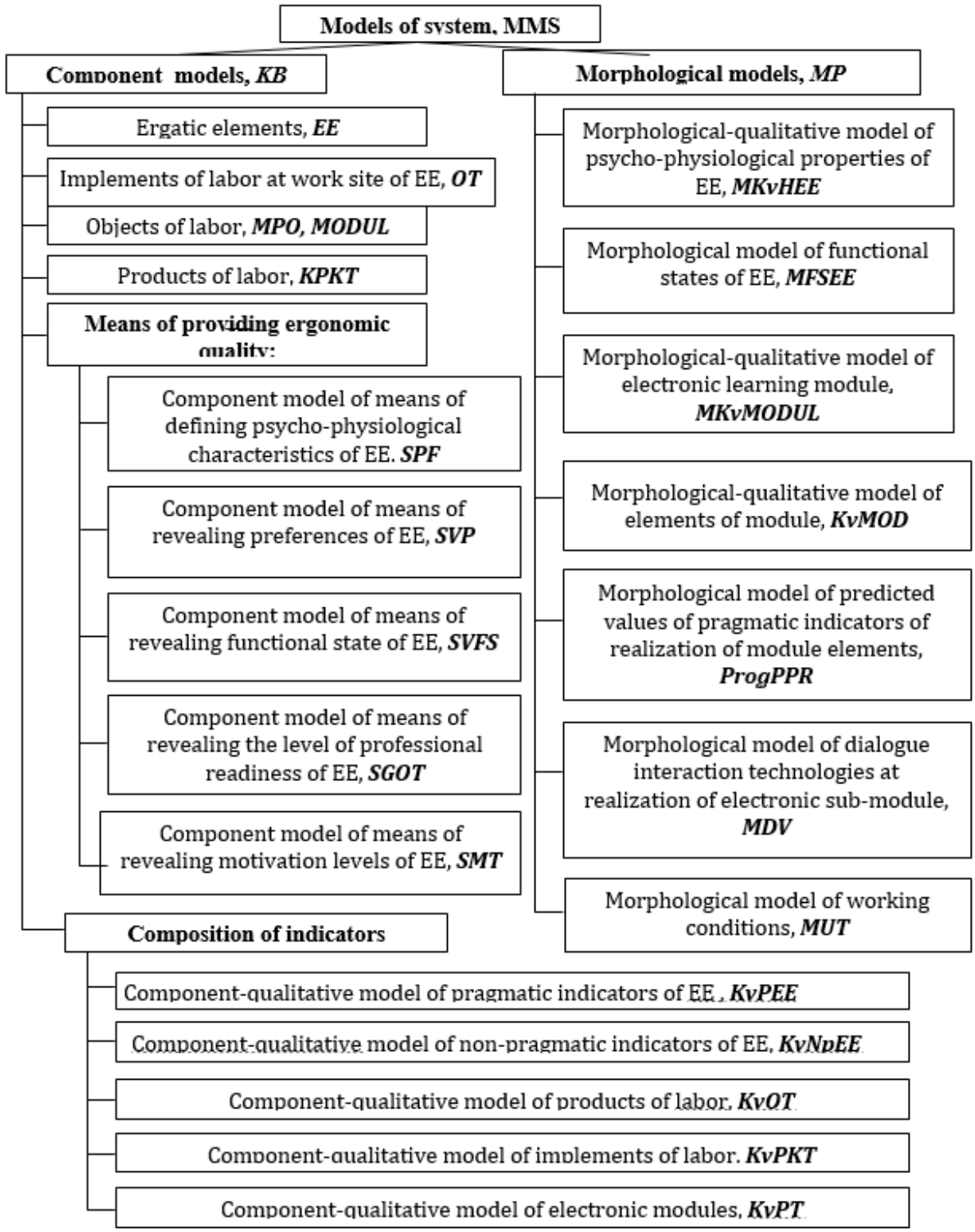


Figure 3: Structure of complex of models of systems ergonomic analysis.

KT_k is the number of themes of the k-th subject area;
$PMod_{il}$ is the first sub-module of the i-th module;
$Srmod_{iln}$ is the n-th self-control of the first sub-module of the i-th module;
KSr_{il} is the number of variants of self-control of the first sub-module of the i-th module;
$Sdmod_{ilk}$ is the z-th means of "finishing" of additional learning (in terms of [15] – "finishing") of the first sub-module of the i-th module;

KSd_{il} is the number of means of "additional learning" of the first sub-module of the i-th module;
$KPmod_i$ is the number of sub-modules of the i-th module;
$Pruk_{il}$ is a sign of existence of means of controlling the quality level (provides a possibility of changing learning technologies depending on the current level of the learning quality) of the first sub-module of the i-th module, $Pruk_{il}$ [0,1].

Component model of the means of revealing motivation levels. The model gives enumeration of means for revealing motivation levels of EE.

$$SMT =< [INSmt_i, NameSmt_i, [PSmt_{ij}]|j \in [1, 2, ..., KPMT_i]|i \in [1, 2, ..., KMT]] > \quad (3)$$

where $INSmt_i$ is the identifier of the i-th means of defining motivation of EE;
$NameSmt_i$ is the name of the i-th means of defining motivation of EE;
$PSmt_{ij}$ is the j-th indicator for the i-th means, $PSmt_{ij} \in MMT$;
$KPMT_i$ is the number of all indicators of motivation for the i-th means;
KMT is the number of means of defining the motivation level of EE.

Component model of means of revealing preferences of EE. The model describes the means for revealing preferences and indicators of EE and preference indicators of the EE, revealed by this means.

$$SVP =< INSvp_i, NameVp_i, [PSvp_{ij}]|j \in [1, 2, ..., KPVP_i]|i \in [1, 2, ..., KVP] > \quad (4)$$

where $INSVp_i$ is the identifier of the i-th means of revealing the EE preferences;
$NameVp_i$ is the name of the i-th means of revealing the EE preferences;
$PSvp_{ij}$ is the j-th indicator for the i-th means, $PSvp_{ij} \in [PMOD]$;
$KPVP_i$ is the number of all indicators of the EE preferences, revealed by the i-th means;
KVP is the number of means of revealing the EE preferences.

Component-qualitative model of non-pragmatic indicators of EE. The model defines the composition of the EE characteristics, which are revealed for defining individual preferences, psycho-physiological characteristics, functional state, motivation and level of readiness for learning.

$$KvNpEE =< [PMOD, PFH, [PFS, VPfs], [MMT, VMmt], [InUGot, VUGot]] > \quad (5)$$

where $PMOD$ is the set of characteristics of preferable modalities of the EE;
PFH is the set of psycho-physiological characteristics of the EE;
PFS is the indicator of functional state;
$VPfs$ is the range of values of functional state;
MMT is the level of the EE motivations;
$VMmt$ is the range of values of motivation level;
$InUGot$ is the integral level of professional readiness for learning of EE;
$VUGot$ is the range of values of the level of professional readiness for learning of EE.
The set of characteristics of preferable modalities of the EE are determined by formula:

$$PMOD =< [Pmod_j, VPmod_j]|j \in [1, 2, 3, 4] >$$

where $Pmod_j$ is the name of the j-th characteristic of preferable modalities of EE;
$VPmod_j$ is the range of values of the j-th characteristic of preferable modalities of the EE.
The set of psycho-physiological characteristics of the EE is determined by formula:

$$PFH =< [Npfh_j, Vpfh_j]|j \in [1, 2, ..., Kpfh] >$$

where $Npfh_j$ is the name of the j-th psycho-physiological characteristic of the EE;
$Vpfh_j$ is the range of values of the j-th psycho-physiological characteristic of the EE;
$Kpfh$ is the number of psycho-physiological characteristics of the EE.

Component-qualitative model of implements of labor. The model describes the characteristics of implements of labor, used in the system.

$$KvOT =< [idOt_i, NameOt_i, TipOt_i, [Pk_{ij}, Val_{ij}]|j \in [1,2,...,KPK_i]|i \in [1,2,...,KOT]] > \tag{6}$$

where $idOt_i$ is the identifier of the i-th implement of labor;
$NameOt_i$ is the name of the i-th implement of labor;
$TipOt_i$ is the type of the i-th implement of labor;
Pk_{ij} is the j-th characteristic (quality indicator of the i-th implement of labor);
Val_{ij} is the value of the j-th characteristic of the i-th implement of labor;
KPK_i is the number of all quality indicators of the i-th implement of labor;
KOT is the number of implements of labor.

Morphological-qualitative model of electronic learning module. The model contains the values of the results of ergonomic assessment of learning module quality.

$$MKvMODUL =< idMod; [PO_k; [tema_{kj}]|j \in [1,2,...,KT_k]; [px_i]|i = [1,2,3]; [py_i]| = [1,2]; [pz_i]|i = [1,2]; [pv_i]|i = [1,2,3]; [pm_i]; [mod_i]|i = [1,2,3,4]; e_i|i \in [1,2,3]] > \tag{7}$$

where $idMod$ is the identifier of a module;
PO_k is the k-th subject area;
$tema_{kj}$ is the j-th theme of the k-th subject area;
px_i is the $i-th$ indicator of the interface assessment;
py_i is the $i-th$ indicator of assessment of slide's parameters;
pz_i is the $i-th$ indicator of test assessment;
pv_i is the $i-th$ indicator of assessment of visual environment;
mod_i is the $i-th$ indicator of information modality;
e_j is the result of assessment (resolution on correspondence of a module to ergonomic requirements).

The developed models have defined the concept of forming the knowledge and data bases of the learning management system in the "agent – manager for e-learning" software package [15, 16] (figure 4).

To study the effectiveness of the developed models and computer technology, the experiments were conducted on the basis of Sumy National Agrarian University. The quality expertise and evaluation of the parameters of electronic training modules "Informatics" for first-year students of the specialty "Agronomy" of the Bachelor's educational level were carried out.

The developed technology makes it possible to take into account the factors affecting the students' learning outcomes from a holistic perspective and form an individual trajectory of the learning session.

3. Conclusion

The proposed architecture of the training service based on the use of a personal learning environment and intelligent agent-managers provides users with the opportunity to collect, analyze, distribute and use knowledge in the e-learning system from various independent sources.

The computer technology that enables to automatize the processes of organizing high-quality human computer interaction in e-learning systems has been developed:

- ensuring a focus on comprehensive accounting of factors affecting the students learning outcomes;
- automatic selection of an individual training session trajectory.

The direction for future research:

- development of intelligent agent models based on dynamic data extraction rules and interaction with LMS;

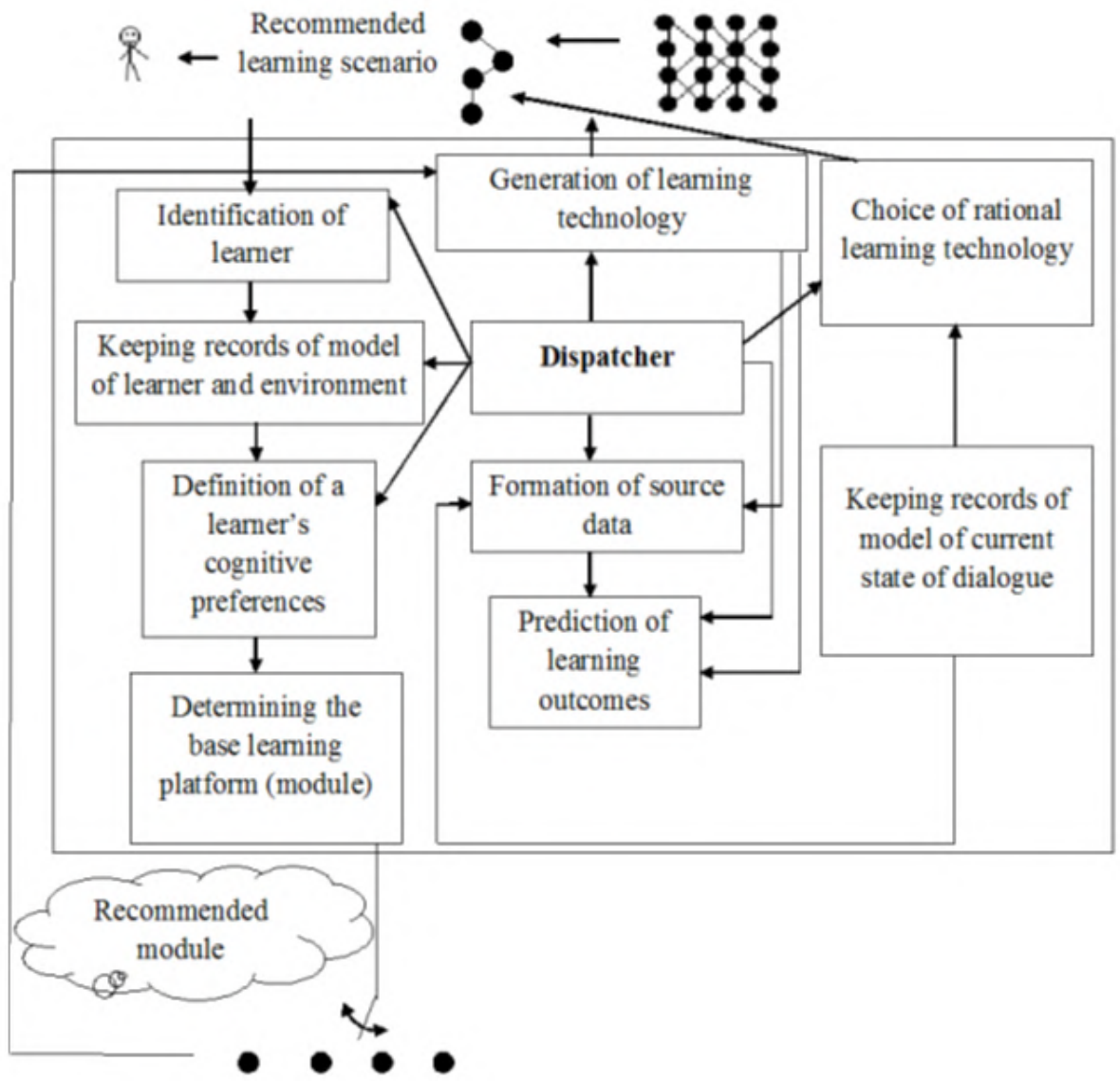


Figure 4: Basic functional blocks and principle of operation of agent-manager for e-learning.

- formation of intelligent agent operation algorithms that automatically detect the student's status, profile, and agent response in real time.

Declaration on Generative AI: The authors have not employed any Generative AI tools.

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Blended learning: definition, concept and relevance to education for sustainability

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Abstract

A review of normative documents and scientific sources on Computer Science teacher training is made. Based on this, the contradictions that actualize the topic of the study are highlighted. The article aims to answer two research questions: 1) What is the appropriate Ukrainian scientific term for "blended learning" given the country's European integration processes? 2) What is the meaning of the term "blended learning"? The analysis concludes that the appropriate Ukrainian scientific term for "blended learning" is "kombinovane navchannia". The article defines blended learning as a planned, pedagogically balanced, adaptive combination, interpenetration, and integration of technologies (face-to-face and distance learning, formal and non-formal learning, real and virtual, individual and collective learning) to optimally meet the educational needs of the subjects of the educational process using intelligent ICTs.

Keywords

blended learning, computer science education, teacher training

1. Introduction

One of the Sustainable Development Goals (SDGs), which is stated in "Transforming our World: the 2030 Agenda for Sustainable Development", is SDG 4: "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" [1, p. 18]. Revealing the ways to achieve SDG4, UNESCO emphasizes that "teachers are the key to achieving all of the SDG4 targets, ... as teachers are a fundamental condition for guaranteeing quality education, [they] should be professionally qualified, and supported within well-resourced, efficient and effectively governed systems" [2, p. 15]. "A holistic and coherent curricular approach will require alignment between curriculum content, assessment, teacher training" [2, p. 18].

The European Commission, in its "2030 Digital Compass: the European Way for the Digital Decade" states that "in just one year, the COVID-19 pandemic has radically changed the role and perception of digitalization in societies" [3, p. 1], and digital technologies have become an imperative in education. The first step on the European path is digital professionals and a digitally literate population capable of recognizing disinformation and defending themselves against cyberattacks, living and working in an information society whose members learn from an early age to understand how to process large amounts of information presented online. Concerning systematic (formal) education and training, the European Commission emphasizes the importance of deep integration of digital technologies into school and university methods and forms of teaching in all subjects. At the same time, personality-oriented digital learning tools create conditions for educational innovation and enable teachers to apply new teaching methods [4].

AREdu 2024: 7th International Workshop on Augmented Reality in Education, May 14, 2024, Kryvyi Rih, Ukraine
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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

CEUR-WS.org/Vol-3918/paper303.pdf

To ensure quality digital education, the European Commission recommends, particularly [4, p. 12-17]:

- support the research, development, and testing of digital educational tools and new technologies, including augmented, virtual, and augmented reality, artificial intelligence, robotics, and the metaverse;
- introduces a mandatory component of professional training for future teachers – "ICT in Education";
- ensure the development of digital competencies of teachers in the system of continuing education;
- recognize and encourage flexible, accessible, and innovative forms of digital professional development, such as online learning, short-term courses, national and international mobility programs, peer learning, collaborative projects, networks, and communities of practice and research;
- reflects the need for digital well-being in teaching and learning and the development of digital technologies and environments to support them;
- invest in high-speed Internet connections to ensure equal access for all students, modernizing digital classroom equipment and providing all teachers with personalized devices (desktop, mobile, or tablet) to enhance their teaching and learning activities, and deploying and integrating relevant centralized services, including cloud-based services, such as learning management systems.

The European Commission in "Council Recommendation on blended learning approaches for high-quality and inclusive primary and secondary education" of November 29, 2021 [5, p. 23], while fully recognizing the value of face-to-face learning, points out that learning in different environments, including school, home, outdoors, cultural sites, workplaces, and digital environments, can motivate children and young people to develop their competencies in general and increase the quality of education and inclusiveness of learning through blended learning approaches. At the same time, using digital technologies provides an opportunity to support learning in different environments and contexts, and the acquisition of the necessary digital and media competencies can be supported through blended learning.

The European Commission recommends the use of blended learning to ensure high-quality primary and secondary education through [5, p. 26]:

- developing blended learning methodologies aimed at ensuring a lasting positive impact on teaching and learning, adapted to the age, abilities, specific needs, and learning goals of students: developing and implementing learning tools, in particular for the development of science, digital and media competencies; supporting learning in different environments; creating an appropriate balance between teacher-led and self-directed learning on the one hand and collaborative learning on the other; developing new learning technologies;
- developing and disseminating training materials for teachers on the organization of blended learning;
- implementation of blended learning in the system of teacher training and retraining;
- establishing expert centres to develop approaches to blended learning and implement best practices;
- supporting the professional development of teachers and educational leaders through massive open online courses on blended learning;
- providing schools with tools and resources for blended learning, as well as guidelines for their effective use;
- developing recommendations for the use of artificial intelligence to improve curricula;
- supporting the development of resources and evidence-based recommendations for pedagogical design and organization of blended learning, including possible digital tools, approaches to learning assessment, data protection, privacy, and security on the Internet.

"Digital Education Action Plan 2021-2027" [6] defines the European approach to education in the digital age and considers the development of digital competencies as a strategic priority. The Digital

Education Action Plan states that a deep understanding of the digital world should be part of formal and non-formal education. This is especially important in the context of digital transformation and the impact of new digital tools, in particular those based on generative artificial intelligence systems.

"Council Recommendation on blended learning approaches for high-quality and inclusive primary and secondary education" [5] calls on EU countries to make efforts to accelerate the development of digital competencies of students and teachers and points out that in primary and secondary education, digital competencies are developed through a combination of different approaches, primarily within a single subject – Computer Science (computational thinking), as well as in the teaching of other STEM disciplines.

In "Council Recommendation on improving the provision of digital skills and competencies in education and training" [7] of November 23, 2023 Computer Science is considered "a distinct scientific discipline characterized by its own concepts, methods, body of knowledge, and open issues. It covers the foundations of computational structures, processes, artefacts, and systems, and their software designs, their applications, and their impact on society" [7, p. 9].

"Council conclusions on European teachers and trainers for the future" [8] emphasize that teachers are a driving force that should be involved in the development of education and training policies and supported through a comprehensive approach to their teacher education, teacher training, and continuing professional development, including digital competencies. In addition, the European Commission's structured dialogue with EU Member States on digital education and digital competencies has highlighted the challenges faced by most Member States in recruiting (attracting), retaining, and training teachers, especially Computer Science teachers (for primary, secondary and vocational education) [7, p. 12].

To improve digital competencies, the European Commission recommends [7, p. 16-20]:

- develop digital competencies in primary, secondary, and vocational education, with a particular focus on acquiring skills to understand digital technologies and to use them safely and responsibly;
- encourage and facilitate the participation of schools in the Digital Education Hackathon and EU Code Week as a means of digital-based cross-curricular integration;
- promote an interdisciplinary approach to the development of digital competencies in different subject areas, especially science, technology, engineering, arts, and mathematics (STEAM) education;
- improve professional orientation activities for the profession of Computer Science teacher (computational thinking) for primary and secondary education and teacher of Computer Science disciplines for higher education with a high level of psychological, pedagogical, and methodological training;
- promote both the involvement of IT professionals in the work of teachers of informatics and the internships of teachers in IT enterprises, as well as their continuous professional development;
- support quality Computer Science education in primary and secondary schools through
  - teaching informatics as a separate school subject based on scientifically sound methodology;
  - providing Computer Science education by qualified teachers with access to quality educational resources;
  - inclusive and balanced teaching of Computer Science;
  - exchange of best practices in Computer Science education.

The commission intends to support reform efforts for digital skills and competencies development and high-quality informatics or computational thinking [7, p. 28].

In previous doctoral thesis research, several problems and tasks related to:

- involvement of students in *combined learning* [9], its impact on student's motivation, performance, and behaviour [10, 11, 12];
- methodologies for course development, assessment [13, 14, 15, 16, 17] and scaling courses for blended learning [18];

- *blended learning* of foreign languages [19], Computer Science [20, 21, 22, 23], mathematics [24];
- *blended learning in vocational education institutions* [25, 11];
- *blended learning of future specialists* in philology [26, 27], physical education and sports [28], information technologies [29, 30, 21];
- *blended learning of future teachers* [31, 32, 33], in particular, foreign languages [34, 35, 36], primary school [37], Computer Science [38];
- *blended learning in teacher professional development* [39, 40, 41, 42];
- *professional training and retraining of teachers to implement blended learning* [43, 44, 45, 46].

At the same time, the analysis of regulatory documents and scientific sources on the research problem made it possible to identify several *contradictions*:

- between the existing European requirements for the professional competencies of Computer Science teachers and the lack of national standards for the training of Computer Science teachers;
- between the potential of intelligent technologies and the lack of methods of their use for the implementation of blended learning;
- between the need to form professional competence in the field of blended learning in future Computer Science teachers and the lack of development of its structure, components, and diagnostic tools.

Resolving these contradictions requires solving the problem of substantiation and developing theoretical and methodological foundations for designing a methodological system of blended learning for future Computer Science teachers, which led to the choice of the research topic.

The author's previous research has attempted to address certain issues in this area, including systematic analysis of scientific sources on the use of blended learning in teacher training and retraining [47, 48], and an analysis of students' needs for distance/blended learning in wartime [49].

The purpose of the article is to substantiate the answer to two research questions:

1. Based on the intensification of European integration processes in Ukraine, which scientific term best corresponds to the term "blended learning"?
2. What is the meaning of the term "blended learning"?

2. Blended learning – *zmishane* (mixed) or *kombinovane* (combined)?

In Ukrainian studies, both the terms "mixed learning" and "combined learning" are often used [50, 51, 52, 53, 54, 55]. The English translation of the word can explain this variation "blended" – mixed or combined. In official documents, the term "mixed learning" is mostly used [56, 57, 58]. Let's analyze the approaches to translating "blended learning" in the free encyclopedia Wikipedia, Wiktionary, and scientific sources (table 1). In this case, the materials from Wikipedia and Wiktionary are used rather to reflect the current state of public opinion.

Here are the generalized results of using different translations of the term "blended learning" on the map (figure 1), where we mark the countries where the term "mixed learning" is used with a red marker, green – "combined learning", blue – "blended learning" and yellow – the own term. We will also map the auxiliary words used to define the term, where countries that use the word "combining" are marked with a green marker, "mixing" with a red marker, and both "mixing" and "combining" with a blue marker (figure 2).

In the Great Explanatory Dictionary of the Modern Ukrainian Language, "combination" means a connection, conjunction, or arrangement of something homogeneous in a certain order [59, p. 558].

"Combined – which is a combination of something" [59, p. 558].

"Mixed – 1) consisting of something different, heterogeneous; 2) lacking the usual order, disorderly; jumbled, mixed up" [59, p. 467].

Table 1: Approaches to the definition of the term “blended learning”.

Language, **concept**	**Definition**	**Concept (words used to define)**
Ukrainian, zmishane navchannia [60, 61, 51, 52, 53, 54], kombinovane navchannia [62, 63, 64]	A type of hybrid methodology that combines online learning, traditional and independent learning. It means not just the use of modern interactive technologies in addition to traditional ones but a qualitatively new approach to learning that transforms and sometimes even “turns” the classroom	mixed learning
Albanian, mësimi i përzier [65, 66]	është një qasje ndaj arsimit dhe edukimit që *kombinon* materiale arsimore në internet dhe mundësi tjera për ndërveprim në internet me metodat tradicionale të mësimdhënies klasore në shkollë	mixed learning (“combining”)
English, blended learning [67, 68, 69, 70]	the *combination* of online educational materials and interactions with traditional classroom teaching	blended learning (“combining”)
Bulgarian, хибридно обучение [71, 72]	*хибридно* или *смесено* обучение е подход в ученето и съответно в педагогиката в образованието, който съчетава онлайн образователни материали и възможности за взаимодействие онлайн с традиционни методи на класната стая или студентска зала, като лекционна среда	гібридне, змішане навчання
Danish, blended learning [73, 74, 75]	er et begreb der anvendes inden for uddannelsesverdenen. Det betegner typisk *kombinationen* af e-learning og tilstedeværelseskurser, f.eks. instruktørledede kurser	blended learning (“combining”)
Estonian, põimõpe [76]	on õppevorm, mille puhul osa õppest toimub lähiõppena ja osa veebiõppena või paindõppena	–
Spanish, aprendizaje semipresencial [77, 78]	el aprendizaje semipresencial (en inglés blended learning o b-learning) se refiere a la *combinación* del trabajo presencial (en aula), y del trabajo en lónea (*combinando* Internet y medios digitales), en donde la persona que es estudiante puede controlar algunos factores como el lugar, momento y espacio de trabajo	semi-present learning (“combining”)
Italian, apprendimento misto [77, 78]	nella ricerca educativa si riferisce ad un *mix* di ambienti d’apprendimento diversi. Esso *combina* il metodo tradizionale frontale in aula con attivit à mediata dal computer (ad esempio apprendimento online, uso di DVD, ecc.) e/o da sistemi mobili (come smartphone e tablet)	mixed, hybrid learning (“mixing”, “combining”)
Catalan, aprenentatge mixt [79, 80]	aprenentatge que *combina* els elements de l’aprenentatge electrònic no presencial i els de l’aprenentatge tradicional a l’aula	mixed learning (“combining”)
Dutch, blended learning [81, 82, 83]	eén definitie is “een *combinatie* van online leren en contactonderwijs”, een andere “een *combinatie* van campusonderwijs en e-learning”	blended learning (“combining”)
German, integriertes lernen [84, 85, 86]	bezeichnet eine Lernform, bei der die Vorteile von Präsenzveranstaltungen und E-Learning *kombiniert* werden sollen	integrated learning (“combining”)

Continuation of the table 1

Language, concept	**Definition**	**Concept (words used to define)**
Norwegian, blandet læring [87, 88]	er et begrep som benyttes innenfor utdanning og betegner vanligvis en *kombinasjon* av flere ulike tilnærminger til læring som e-læring og eksempelvis kurs ledet av en instruktør. Det kan også være ulike *kombinasjoner* som eksempelvis selvstudier, e-læring og gruppediskusjoner via Internett	blended learning ("combining")
Polish, blended learning [89, 90, 91]	mieszana (*zintegrowana*, *hybrydowa*) metoda kształcenia, łącząca tradycyjne metody nauki (bezpośredni kontakt z prowadzącym) z aktywnościami prowadzonymi zdalnie za pomocą komputera (M-learning)	mixed learning (integrated, hybrid learning)
Portuguese, blended learning [92, 93, 94]	é um derivado do e-learning, e refere-se a um sistema de formação onde a maior parte dos conteúdos é transmitido em curso à distância, normalmente pela internet, entretanto inclui necessariamente situações presenciais, daí a origem da designação *blended*, algo *misto*, *combinado*	blended learning, mixed, combined learning
Romanian, învăţare mixtă [95]	reprezintă procesul încorporării a diverse stiluri de învăţare, care se pot realiza prin intermediul resurselor fizice şi virtuale *mixte*	mixed learning
Serbian, mešano učenje [96]	obrazovni program (formalni i neformalni) koji *kombinuje* onlajn digitalne medije sa tradicionalnim metodama koji se koriste u učionici. Ono zahteva fizičko prisustvo i nastavnika i učenika. Učenici i dalje pohađaju tradicionalne škole u kojima je prisutan nastavnik, ali "lice u lice" predavanja su *kombinovana* sa aktivnostima na kompjteru	mixed learning ("combining")
Slovak, kombinované vzdelávanie [97, 98]	*kombinácia* štandardnej výuky (prezenčnej, prezentačnej, face-to-face) s e-learningom. *Kombinované* vzdelávanie sa snaží kompenzovať niektoré nevýhody e-vzdelávania pri plnení vzdelávacích cieľov *kombináciou* s prvkami štandardnej výuky, kedy je napríklad *kombinovaný* v distančnom štúdiu e-learningový kurz s úvodným či záverečným seminárom alebo workshopom. Tento prístup je vhodný predovšetkým tam, kde cieľová skupina nie je zvyknutá používať moderné komunikačné nástroje, ako je chat, diskusné fórum, videokonferencie a pod	combined learning
Slovenian, kombinirano učenje [99, 100, 101]	koncept učenja in poučevanja, pri katerem se spajajo in *mešajo* različni učni slogi in se uporabljajo najrazličnejši učni pripomočki – od virtualnih do fizičnih. Učni slogi se nanašajo na številne različne načine, ki jih ljudje uporabljajo pri učenju. *Kombinirano* učenje prav učnim slogom daje prednost: na eni strani z vključevanjem najrazličnejših nalog in dejavnosti v pouk, na drugi pa z uporabo računalniške tehnologije, e-gradiv, interakcije med mentorjem in udeleženci ter med samimi udeleženci učnega procesa oz. tečaja	combined learning ("mixing")

Continuation of the table 1

Language, concept	**Definition**	**Concept (words used to define)**
Hungarian, blended learning [102, 103, 104]	egy újabb oktatási forma, amelyben az internet és a digitális média nyújtotta lehetőségeket és a hagyományos tantermi oktatás módszereit együttesen használják. Tananyag elsajátítása közben az oktató ellenőrző és segítő szerepe megmarad: ebben a modellben fontos szerepet kap a személyes kontaktus, az órák megadott helyén és idején való személyes részvétel, míg az online tér tanulástámogató felületein keresztül a diákok szintén kapcsolatba léphetnek a tanárokkal és egymással is	blended learning
Finnish, sulautuva oppiminen [105, 106, 107]	tarkoittaa oppimisen ympäristöjen sulautumista. Oppimisympäristön sulattaminen tarkoittaa esimerkiksi sitä, että luokkahuone ja virtuaalinen oppimisympärist ö sulautetaan yhdeksi kokonaisuudeksi, jossa oppiminen tapahtuu. Usein opetuksen sulauttaminen tarkoittaa, että sulautetaan synkronista ja asynkronista opetusta	–
French, apprentissage hybride [108, 109, 110]	est une formule pédagogique qui résulte d'une *combinaison* de séquences de formation en ligne (e-learning) et de formation en présentiel. Elle offre certains avantages comme un espace de travail plus collaboratif pour les apprenants. L'utilisation des technologies de l'information et de la communication donne l'opportunité à l'apprenant d'avoir, dans une certaine mesure, un contrôle sur le temps, le lieu, les moyens et la vitesse1. À ce titre, on distingue l'apprentissage synchrone: les formateurs et les éléves suivent en même temps un module de formation et asynchrone : les éléves suivent de façon différée grâce à des ressources pré-établies par l'enseignant (vidéo, diaporama, contenu interactif...)	hybrid, mixed learning ("combining")
Czech, blended learning [111, 112, 113]	označení pro kombinovanou výuku, tedy pro kombinaci standardní výuky (prezenční, prezentační, face-to-face) s e-learningem. Jedná se o specifickou formu vzdělávání, která kombinuje tradiční metody výuky s online studijním obsahem. Využívá různé kombinace tradižního vzdělávání tváří v tvář (face-to-face), e-learningu a individuálního vzdělávání vlastní rychlostí (self-paced learning). Účelem je, aby se jednotlivé metody navzájem doplňovaly	blended learning ("combining")
Swedish, blended learning [114, 115, 116]	avser just en blandning av olika lärmiljöer. Blended learning *kombinerar* traditionella klassrumsmetoder med mer moderna datormedierade aktiviteter	blended learning ("combining")

According to the Law of Ukraine "On Education" [117] "educational process – a system of scientific, methodological and pedagogical measures aimed at developing a personality through the formation and application of its competencies".

"System" is an order caused by the correct, systematic arrangement and interconnection of something [59, p. 1320].

The analysis made it possible to answer the first research question: based on the intensification of European integration processes in Ukraine, the scientific term that best corresponds to the concept of "blended learning" is "kombinovane navchannia (combined learning)".



Figure 1: The term "blended learning" on the European map: the red marker indicates countries where the term "mixed learning" is used, the green marker indicates "combined learning", the blue marker indicates "blended learning", and the yellow marker indicates its own term.

3. Is blended learning a form, a method, a technology, a learning strategy, or what?

In a critical review, Oliver and Trigwell [118] concluded that the term blended learning simply requires two or more different kinds of things that can be combined. It is argued that the breadth of interpretations means that almost anything can be considered blended learning. Driscoll [119] also states that blended learning uses several components. It can be a combination of methods based on web (online) technologies, pedagogical approaches, learning technologies, and face-to-face learning meetings, and the following combinations can be considered: e-learning with traditional learning, online learning with face-to-face learning, combination of media, combination of learning theories, methods, etc.

According to *National Education Act of blended learning 2542* [120], blended learning is learning that combines the benefits of classroom (face-to-face) instruction with online learning for content delivery, activities, and assessment.

Cross and Moore [121] define blended learning as a stepping stone to the future, and Rossett and Frazee [122] note that blended learning integrates seemingly opposing approaches such as formal and informal learning, face-to-face and online learning, self-directed and guided learning, and digital reference materials and face-to-face contact to achieve individual and institutional [learning] goals.

Graham [68] identifies three common definitions of blended learning: "a combination of forms of



Figure 2: Definition of "blended learning" on the European map: countries that use the word "combining" are marked with a green marker, "mixing" with a red marker, "mixing" and "combining" with a blue marker.

learning (or means of learning), a combination of learning methods, and a combination of face-to-face and online learning".

Hubackova and Semradova [123] characterize blended learning as "a combination of face-to-face (contact) learning with a teacher and self-directed learning using online learning" [123, p. 551].

Many studies determine that the primary goal is to ensure that face-to-face and online teaching and learning complement each other, combining different advantages (Bicen et al. [124], Çakır and Bichelmeyer [125], Deschacht and Goeman [126]).

Garrison and Kanuka [127] interpret blended learning as "deliberate integration of face-to-face learning activities with online learning" [127, p. 96].

Allen and Seaman [128] define "blended learning course as a course that combines online and face-to-face learning. Much of the content is delivered online, online discussions are commonly used, and there are usually fewer face-to-face meetings. Similarly, Hrastinski [115], notes that all types of education that contain some aspects of face-to-face and online learning can be defined as blended learning.

Allen et al. [129], Bonk and Graham [70], Khlaisang [130, 131], Waterhouse [132], Wilson and Smilanich [133] define the following ratio of online and face-to-face learning – 30-79% online and face-to-face learning at the level of 21-70%; Bernardet al. [134], Porter et al. [135] estimate that at least 50% of the total learning time should be face-to-face. Diep et al. [136] distinguish two different approaches to blended learning, one of which contains 25% online learning, the other – 50% online. Online courses are defined as those that provide at least 80% of the content online [129, p. 5]. In [137, p. 2] it is noted that "as e-learning has become an agent of global change in higher education, it has

become more diverse in its form and application". "This diversity complicates the ability to share research findings and best practices, as there is a lack of a common set of definitions to distinguish between the many variations in the field of e-learning" [138].

Ultimately, Shibley [139] states that "the advantage of blended learning is that the variety of combinations of face-to-face and online combinations is seemingly endless. In all cases, however, the goal is to use technology to make face-to-face learning more effective than it would be without online enhancements" [139, p. 6]. Finally, it is up to the teacher to decide what is taught face-to-face and what is taught online.

Blended learning encourages independent, autonomous, self-regulated, and collaborative learning (Ruiz Bolívar [140]), and blended learning involves both face-to-face and virtual (online) classes, which leads to interactivity and motivation through the collaboration of students and teachers (Gonzalez Aldana et al. [141, p. 145]).

Blended learning includes a face-to-face mode to help students clarify their issues, and teachers further enhance the level of mastery of the course (Gonzalez Aldana et al. [141, p. 147]).

When comparing blended learning and e-learning, scholars determine they have somewhat similar characteristics: physical separation of students and teachers, use of ICT tools, and independent learning. However, e-learning is based on online learning with the use of ICT tools, and blended learning uses ICT tools to develop the learning process best (Estrada Lizárraga [142]). In e-learning, a lower success rate is achieved because distance learning does not include dynamic collaboration processes, which allows for a high non-completion rate. Since online consultations are not sufficient to cover all students' questions, the interaction between teacher and student is lost (Antúnez Sánchez et al. [143]). Blended learning provides an opportunity for students to interact more with both peers and teachers – not all classes are online; some are face-to-face, but the student has a flexible schedule. Jachin and Usagawa [144] define that "e-learning is becoming a driving force for pedagogical and technological innovations in the world's higher education institutions. The most practical form of e-learning in higher education is blended learning". Picciano [145] adds that "interestingly, there are few estimates of the number of students enrolled in blended learning courses. Although it is generally recognized that blended learning fits well into the mainstream of American higher education, there is no data to document this. Why is this so? First, blended learning has become so widespread that many teachers do not necessarily identify themselves as blended learning teachers when in fact they are... The mystery and aura of teaching online that existed in the mid to late 1990s is disappearing". Masie [146] observes that the ""e" in e-learning is disappearing, and it's all just learning". "Second, it is difficult for colleges and universities to keep accurate records of faculty teaching blended learning courses" [145].

Highly appreciating the role of ICT (both hardware and software), "National Education Act of B.E. 2542" [120] also emphasizes the importance of communication, assessment, the role of the teacher/student, and the methodology itself.

Galvis [137] expands on the above definition and characteristic features of blended learning: learning takes place in different learning environments – formal (e.g. classroom), informal (e.g. workplace, communities of practice), and informal (e.g. media, websites), based on the strengths of each. It also emphasizes the role of ICT – "the decisive role in blended learning is played not only by the teacher but also by ICT technologies[137]. Blended learning provides great opportunities for learning the subject. Thanks to ICT tools, students have a high level of satisfaction (up to 90%) [141, p. 146].

Blended learning means more than a simple combination of components, and the purpose of using this combination is to make the learning process as convenient as possible, while at the same time stimulating students to learn in other ways (Picciano [145, p. 4]).

Analyzing blended learning, Jachin and Usagawa [144, p. 1482] conclude that the most common reason for choosing blended learning is that it combines the "best of both worlds" (face-to-face and online learning).

Procter [147, p. 3] emphasizes that blended learning requires "an effective combination of different learning modes, models, and styles".

Summarizing the research of Dick et al. [148] and Holden et al. [149] in Mirriahi et al. [150], they define blended learning as the process of integrating the most appropriate learning and teaching

strategies, technologies, and/or tools to provide meaningful, flexible learning activities to achieve results.

The goal of blended learning is to provide more flexibility and focus on educational comfort, where the student can learn dynamically and get a positive result. In the learning process, the teacher and student are physically separated. In this mode, the student starts learning independently. The main features of blended learning are its adaptability, emphasis on the development of cognitive skills, improving understanding and application of acquired skills, solving future problems, making decisions using ICT, speed in communication, development and updating of content (Gonzalez Aldana et al.[141, p. 147]). "Blended learning is the most favourable form of learning at all educational levels, as it covers different areas of the educational process, facilitating the perception of course content by students" [141, p. 147].

In higher education, blended learning has become widespread due to its flexibility, which allows teachers to integrate various educational technologies into the educational process. In addition, teachers can offer more effective teaching by implementing student-centred learning. Students can access content anywhere and anytime (Khlaisang and Likhitdamrongkiat [151, p. 760]). They can participate and exchange ideas, both face-to-face in the classroom and in an online environment. In this way, teachers can improve students' cognitive skills and attitude towards face-to-face learning.

Personalization with blended learning is also emphasized by Hubackova and Semradova [123, p. 552], noting that "the main advantage of blended learning is an individualized learning environment. Each student chooses his/her own pace, place, and time, which is most favourable for learning. Immediate feedback plays an important role. Blended learning provides verification of the learner's efforts and an overview of the results achieved. It often makes it possible to compare anonymously with other learners. This fact is highly appreciated by them".

Among the benefits of blended learning, Zacharis [152] cites the following: "Blended learning facilitates learning outside the classroom since the teacher and students have limited time in the classroom, the lesson can be continued online".

Other examples of such examples include "preparing for face-to-face activities, such as flipped classroom, video lectures at home so that the time spent in the classroom is maximized for discussing the subject and for student-centered activities (e.g., group work)" (Tan and Hew[153]).

The analysis conducted by Torres-Coronas and Vidal-Blasco [154] synthesizes the opinions of the main stakeholders of the educational process in higher education institutions: management, students, and teachers. The study shows that blended learning improves the quality of student learning, strengthens academic performance, and encourages the teaching staff to innovate in the educational process continuously.

The goal of blended learning is to maximize the benefits of both face-to-face and online learning (Pavla et al. [155]), and Shibley [139, p. 5] adds that "blended learning is not just a way to minimize face-to-face learning...a well-designed course creates learning opportunities that did not exist before. Derntl and Motschnig-Pitrik [156], Garrison and Kanuka [127], and Twigg [157] agree that simply adding technology to a traditional classroom does not make blended learning effective.

Jachin and Usagawa [144] argue that the use of blended learning in higher education institutions can increase the quality of learning. Developing and implementing BL courses in a specific situation, as well as reviewing and evaluating the quality, will not only allow sharing the experience with similar higher education institutions but will also contribute to general quality research in higher education.

In [158], it is noted that the integration of face-to-face and online learning contributes to the improvement of face-to-face learning. Blended learning improves student engagement through online activities and increases efficiency by reducing lecture time.

At the same time, implementing blended learning is a challenge for teachers with low digital competence (Mirriahi et al. [159]). Therefore, teachers need help with professional development, including demonstrating the benefits of blended learning (Chen et al. [160]). It is also necessary to recognize that 'innovation does not happen without tension, and in fact, it is a tension that provides some of the energy that can drive innovation (Owen and Dunham [161, p. 100]).

Among the disadvantages of blended learning, other scholars also highlight its sometimes inadequate understanding by students, the difficulty of using it in some educational fields, dependence on technological equipment, and again, high requirements for teacher training (Hubackova and Semradova [123,

p. 552]).

Galvis [137] emphasizes both individual teacher initiatives and the need for institutional support for blended learning to "rethink the fundamental processes present in the education value chain, aligning technological, administrative and financial support processes with these fundamental processes by the desired combination parameters" [137, p. 9].

Shibley [139, p. 4] identifies several important emphases in the organization of blended learning, which can be briefly defined as the triad of motivation-assessment-learning activities.

Dziuban et al. [162] define blended learning as a pedagogical approach that combines the effectiveness and socialization opportunities of the classroom with the technologically enhanced opportunities for active learning in the online environment rather than as a ratio of learning modes. In other words, blended learning should be seen not just as a temporary construct but rather as a fundamental redesign of the learning model with the following characteristics: personalization of learning (moving from lecture to student-centred instruction; increased interaction between student-teacher and among students, and effective assessment mechanisms.

The review provided an opportunity to answer the second research question about the content of the concept of "blended learning": **blended learning** is a planned, pedagogically balanced, adaptive combination, interpenetration and integration of technologies (face-to-face and distance learning, formal and non-formal learning, real and virtual, individual and collective learning) to optimally meet the educational needs of the subjects of the educational process using intelligent information and communication technologies.

A central aspect highlighted in this definition is the role of intelligent technologies, such as machine learning models and methods for processing big data in the educational process. These technologies hold the potential to predict potential crises at the learner and system levels, enabling adaptive and personalized learning experiences:

1. Learning analytics and personalization intelligent ICTs like machine learning models can analyze data on learner activities, engagement, emotions, stress levels, etc., to enable individualization and personalization of learning paths, activities, and assessments based on each learner's needs [163, 164].
2. Automated support and feedback AI systems can automatically monitor online sessions, identify patterns of interest/disengagement and provide customized support, feedback and interventions in real-time to keep learners engaged and on track [165].
3. Virtual and immersive learning technologies like virtual reality, augmented reality and AI-driven simulations can create highly immersive and experiential learning environments, especially valuable for domains like computer science, which require interaction with abstract concepts [166, 167]
4. AI-powered tutoring systems can guide learners through concepts, provide step-by-step problem-solving support, and adapt their inputs based on the learner's knowledge state [168].

4. Conclusions and prospects for further research

The answers to the research questions obtained in the course of the study made it possible to define blended learning terminologically as combined learning and content-wise as a planned, pedagogically balanced, adaptive combination, interpenetration and integration of technologies (full-time and distance learning, formal and non-formal learning, real and virtual, individual and collective learning) to optimally meet the educational needs of the subjects of the educational process using intelligent technologies.

Implementing blended learning provides access to big data on the educational process and the possibility of using intelligent technologies (primarily machine learning models and methods) to process them and predict possible crises at the level of learners and the system. In particular, intelligent technologies make it possible to determine the degree of interest of participants in an online class, their emotional state, stress level, etc., which creates conditions for automating individualization and personalization of learning. Therefore, the main concepts that need to be considered for developing a

blended learning system should be personalization of learning, intellectualization, big data, learning analytics, virtualization of learning, and immersion based on student experience.

Accordingly, it is planned to study the following dimensions of blended learning: philosophical – the ratio of real and model (virtual) in learning; psychophysiological – individualization of learning based on the emotional state, stress level, etc; sociological – the ratio of individual and collective, face-to-face and distance learning, desired and forced mobility of learners; organizational and pedagogical – the ratio of formal and informal learning; information technology – the ratio of traditional and intelligent technologies in learning, accessibility and scientificity, real and virtual visibility; synergistic – the ratio of classical machine learning methods and methods of studying complex systems to identify crisis phenomena.

Acknowledgments: I express my sincere gratitude for the help, inspiration, and support of my scientific advisor, Serhiy O. Semerikov.

Declaration on Generative AI: The authors have not employed any Generative AI tools.

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AI tools for sustainable primary teacher education: literary-artistic content generation

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Abstract

The rapid advancement of artificial intelligence (AI) has transformed various sectors, including education. This study explores the possibilities of using AI tools for generating literary-artistic content in preparing primary school teachers for professional activities. The research aims to determine the familiarity and readiness of future primary school teachers to use AI in the literary field, reveal the possibilities of applying AI to prepare teachers for organizing the study of literary works, describe AI tools that can motivate young students to read, and highlight the advantages and disadvantages of using AI programs to generate literary-musical and video content based on literary material. The study employed a mixed-methods approach, combining surveys, hands-on experiences with AI tools, and the analysis of student-generated artifacts. The participants were 138 bachelor's students specializing in "Primary Education" at Borys Grinchenko Kyiv Metropolitan University. The AI tools were introduced and integrated into the teacher preparation curriculum, and data were collected through surveys, pedagogical cases, multimedia didactic tools, and observations. The findings demonstrate the potential of AI tools in creating engaging and interactive literary-artistic content, facilitating personalized learning, and supporting the development of students' creativity and critical thinking skills. The study underscores the importance of integrating AI technologies into teacher education programs to foster digital literacy skills, promote innovative teaching methods, and cultivate a mindset of continuous learning and adaptation. However, challenges and limitations were identified, such as the need for content validation, technical support, and addressing ethical concerns. The study proposes measures to ensure the responsible and beneficial implementation of AI in primary education, including rigorous content validation processes, teacher training, and the development of clear policies for transparent and ethical AI usage. The findings contribute to the advancement of sustainable education practices by preparing future primary school teachers to effectively harness the potential of AI technologies while navigating the challenges and opportunities presented by the digital age. Further research is necessary to explore the long-term impact of AI integration on student learning outcomes, develop comprehensive AI competency frameworks, and refine ethical guidelines for AI use in educational settings.

Keywords

generative AI, primary teacher education, literary-artistic content generation

1. Introduction

1.1. The problem statement

The modern world is rapidly becoming digitalized. Cutting-edge digital technologies are actively used in virtually all spheres of human life, radically transforming the educational space as well. Recently, artificial intelligence (AI) has gained particular popularity. Virtual assistants like Siri and Alexa,

AREdu 2024: 7th International Workshop on Augmented Reality in Education, May 14, 2024, Kryvyi Rih, Ukraine
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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

CEUR-WS.org/Vol-3918/paper304.pdf

automatic organization of information sources on the internet, content curation in social networks, autonomous vehicles, and other robotics no longer surprise many. On the one hand, interest in artificial intelligence is driven by people's changing lifestyles and work habits, and AI has become an integral part of our daily lives. On the other hand, the interest of researchers and developers in digital platforms is fueled by the unlimited and not fully explored possibilities of AI.

Importantly, artificial intelligence is also becoming a leader in the educational sector. Its capabilities are actively applied to improve teaching and learning methods, including automating the routine work of teachers in grading tests and modernizing the creation of lesson plans and new digital didactic tools for education [1]. For instance, the educational platform "Na Urok" already features an "AI Assistant". This is a personal assistant for modern teachers, developed according to the needs of contemporary Ukrainian educators. It includes a set of innovative AI-based tools designed to optimize teachers' daily work. Teachers can generate new school projects, engaging assignments, various exercises and tests, and didactic lesson tools (such as tables, presentations, and flashcards) on this platform. For organizing student work, AI can generate checklists on a given topic and help find interesting arguments and motivation for studying a particular subject. The platform also supports media-related tasks: generating images on a specified topic in a characteristic AI style, voicing given text, transforming scanned copies or photos into text, transcribing the content of videos from provided links, and removing backgrounds from any image. AI makes it possible to organize chats based on the content of a given file, the content of a video, or even a chat with a famous figure. The "AI Assistant" on the "Na Urok" website ensures quick active searches for teachers, including creating collections of images on a given topic, selecting the best videos on YouTube by topic [2], and providing professional collections of materials for work in grades 1-4 under the New Ukrainian School (NUS) curriculum.

Thus, the range of AI applications in teachers' work is broad. The remarkable role of artificial intelligence in education, its ability to generate texts, music, and videos for creating new-format educational materials, underscores the relevance of studying AI as a means of generating literary and artistic content in preparing primary school teachers for professional activities.

1.2. Contribution to sustainable education practices

The use of AI tools for generating literary-artistic content in preparing primary school teachers aligns with the principles of sustainable education. By integrating these innovative technologies into teacher education programs, we aim to foster the development of essential skills and attitudes that contribute to long-term educational sustainability:

- Engaging pre-service teachers in the use of AI tools enhances their digital literacy skills, preparing them to navigate and harness the potential of emerging technologies in their future classrooms [3].
- AI-generated literary-artistic content offers new possibilities for creating interactive and immersive learning experiences. By exposing pre-service teachers to these innovative teaching methods, we encourage them to adopt creative and engaging approaches that can captivate and motivate young learners, thus promoting sustainable student engagement and achievement [4].
- Integrating AI tools into teacher preparation programs nurtures a mindset of lifelong learning and adaptability among future educators. As AI technologies continue to evolve, teachers who are using these tools will be better equipped to continuously update their practices and adapt to the changing needs of their students, contributing to the long-term sustainability of education [5].

1.3. Literature review

Interest in the use of artificial intelligence in education is rapidly growing, as evidenced by statistical data from 2010 (100 publications in Scopus per year) to 2023 (677 publications in Scopus per year) [6]. The application of AI in teaching primary school students has been explored in various aspects. For

instance, Pareto [7] researched the effectiveness of using AI-based games in an educational environment designed to develop mathematical competence (learning mathematical concepts, developing mathematical thinking, etc.) in young students. The use of AI-powered gamification for introducing questions, particularly for teaching mathematics, language, and the study of the surrounding world to students with special educational needs, is discussed by YanFi et al. [8]. Jauhiainen and Guerra [9] demonstrated that ChatGPT, as an example of generative AI, can be used to personalize educational materials according to the knowledge and skills of students with different proficiency levels. The authors highlighted the powerful potential of using generative AI in school education, justifying motivatedlearning and skill development among students. The topic of using artificial intelligence for implementing adaptive learning has been analyzed by Lhafra and Abdoun [10], and Krumsvik [11]. A significant number of studies are devoted to the use of artificial intelligence in STEM education. Specifically, Mehdipour et al. [12] describe the use of a system in primary schools that consists of an AI-supported mobile robot, STEM storytelling, and a content-sharing platform.

The issue of using artificial intelligence as many researchers address a teacher's assistant. Particular attention is given to using ChatGPT to reduce teachers' workload, prevent professional burnout [13], and assist in creating e-learning courses [14]. The study of teachers' awareness of AI features and methods of its application is the focus of research by Prothero [15]. The author notes that among the surveyed teachers, 10% used AI in their work at a basic level, and 15% used AI at a household level but lacked sufficient knowledge to apply AI in their professional activities.

Morze et al. [6] conducted a survey of primary school teachers regarding their understanding of AI, ways to use it as their assistant, the advantages and disadvantages of artificial intelligence, and its development prospects, as well as its application in all areas of human activity. The authors accurately identified the areas where artificial intelligence can act as a teacher's assistant, including content creation, digital tools, communication, assessment, educational materials creation, and research. In the work of Palamar and Naumenko [16], a list of popular AI technologies is provided, and the current state of their application by higher education students is investigated. The article presents the results of a survey of students at the Faculty of Pedagogical Education at Borys Grinchenko Kyiv University regarding the peculiarities of AI technology used by higher education students. The authors discussed the advantages and negative consequences of using AI in the education system. They described the ethics of AI use concerning adherence to the principles and norms of academic integrity [16].

Recent studies have examined the ethical considerations and potential threats of AI in primary education. Alawneh et al. [17] proposed a comprehensive framework that amalgamates privacy-preserving protocols, bias mitigation strategies, and inclusivity measures to address pressing ethical concerns in AI implementation in primary education. Longo [18] discussed the dystopian threat of irresponsible and uncontrolled AI incursion into primary schools, suggesting a utopian postdigital ecopedagogy as a potential remedy.

Several studies have focused on the practical applications and efficacy of AI in primary education. Sperling et al. [19] explored the rationales and practices of introducing machine learning and AI in Swedish primary schools, highlighting the need for continued re-negotiations in the process of automation and personalization. Yuan [20] conducted an experimental study on the effectiveness of AI chatbots for English as a Foreign Language (EFL) learning in a Chinese elementary school, demonstrating significant improvements in oral English proficiency and willingness to communicate.

The preparation and training of primary school teachers in AI competencies have also been addressed in recent research. García-Delgado et al. [21] designed, validated, and implemented a competency-based AI training program for primary education teachers in Spain. Lozano and Blanco Fontao [22] assessed the perceptions of primary education degree students on the irruption of AI tools like ChatGPT in education, highlighting the need for digital literacy at all educational levels.

Researchers have also explored the potential of adapting K-12 approaches for developing AI literacy in adult professionals. Kaspersen et al. [23] conducted an in-vivo explorative case study on adopting child-computer interaction (CCI) approaches for upskilling workers through a full-day workshop, identifying self-efficacy and empowerment as major challenges for AI literacy across sectors.

AI-based personalized learning and learning style prediction in online learning environments for

primary education have also been investigated. Pardamean et al. [24] developed and measured the impact of an AI-based learning style prediction model in an online learning portal for Indonesian primary school students, demonstrating improved learning performance through personalized material recommendations.

Despite the growing body of research on AI applications in primary education, there remain gaps and limitations in the existing literature. Many studies focus on specific AI tools or applications, lacking a comprehensive overview of the various ways AI can be integrated into primary education. Additionally, while some studies address the preparation and training of primary school teachers in AI competencies, there is a need for more research on the development and evaluation of effective training programs.

This study aims to address these gaps by providing a broad exploration of the possibilities of using AI tools for generating literary-artistic content in preparing primary school teachers for professional activities.

1.4. The aim of the research

Therefore, artificial intelligence has become the most progressive technology of today, with its potential being harnessed to develop innovative processes in education. Consequently, there is a need to test various AI digital tools in the educational activities of future educators for their professional development. One of the applications of AI in the professional activities of primary school teachers is the generation of content for creating multimedia didactic tools. This is important for organizing the study of literary works in literature reading lessons in primary school. Reading is a crucial element in personal development. Students acquire new knowledge and aesthetic experiences through active reading activities and develop critical thinking. Reading, emotional perception, and analysis of literary texts contribute to developing communicative competence, particularly active vocabulary, coherent speech, and emotional intelligence.

Attracting modern children's attention to literary books is becoming increasingly complex. Young people spend a lot of time on network entertainment and prefer multimediameans: watching clips, listening to music, and watching films/cartoons/videos. Reading a book requires time and patience, the activation of analytical activities, and a developed reading culture. Therefore, preparing pedagogical cases for future teachers with professional methods to activate reading activities in literature reading lessons using various media is important.

This *article aims* to explore the possibilities of using artificial intelligence tools for primary school teachers' work with literary texts and creating didactic tools for the literary education of young students. To achieve this goal, the following tasks were identified: determine the level of familiarity and readiness of future primary school teachers to use artificial intelligence in the literary field; reveal the possibilities of applying AI to prepare primary school teachers for organizing the study of literary works; describe AI tools that can be useful for future teachers to motivate young students to read; highlight the advantages and disadvantages of using AI programs to generate literary-musical and video content based on literary material.

2. Methodology

Innovative technologies help diversify, modernize, and enrich the presentation of educational material to students. However, the application of artificial intelligence directly depends on the creativity and inventiveness of the teacher. Therefore, during the preparation of future primary school teachers, a study was conducted on the knowledge of higher pedagogical education students about AI tools and their motivation to use them in professional activities, particularly in the literary field.

This study employed a mixed-methods approach, combining both qualitative and quantitative data collection and analysis. The research was conducted in two stages:

1. A survey was administered to students to assess their knowledge of AI tools and their motivation to use them in their professional activities, particularly in the literary field.

2. Students specializing in "Primary Education" were asked to test a set of AI tools for generating literary-musical and video content based on literary material, describe the advantages and disadvantages of AI programs, and prepare pedagogical cases for using multimedia didactic tools created with AI for literature reading lessons in primary school.

The study involved 138 first-level (bachelor's) students in the "Primary Education" specialty, both full-time and part-time, at Borys Grinchenko Kyiv Metropolitan University. Participants were selected using a purposive sampling method, targeting students who were preparing to become primary school teachers.

The AI tools were introduced and integrated into the teacher preparation curriculum as follows:

- students were provided with a comprehensive overview of various AI tools suitable for generating literary-musical and video content, such as Suno, Udio, Boomy, Pictory, Lumen5, and InVideo AI;
- tutorials and demonstrations were conducted to familiarize students with the functionalities and features of each AI tools
- students were given hands-on experience using the AI tools to create multimedia didactic tools based on literary material;
- discussions and reflections were facilitated to explore the pedagogical implications and potential applications of AI-generated content in primary education.

Data were collected through a combination of surveys, student-generated artifacts (pedagogical cases and multimedia didactic tools), and observations. The survey data were analyzed using descriptive statistics to determine students' knowledge and motivation levels regarding AI tools. The qualitative data from student artifacts and observations were analyzed using thematic analysis to identify patterns, advantages, disadvantages, and challenges in using AI tools for generating literary-artistic content.

One of the main challenges encountered during the study was the varying levels of technological proficiency among students. To address this, additional support and guidance were provided to students who required assistance in navigating and using the AI tools effectively. Another challenge was the limited time available within the curriculum to fully explore the potential of AI tools. This was addressed by prioritizing the most relevant and user-friendly tools and providing students with resources for further exploration beyond the classroom.

3. Results

Literary content is organically integrated with artistic content, so students were advised to use exciting and interactive applications such as Suno, Udio, and Boomy. The primary function of Suno (https://suno.com/) is song generation. This AI tool allows the creation of songs based on specified keywords and generates content descriptions (figure 1). The program is configured to create the song's lyrics and music. However, the user can choose the music style and write their own lyrics. It is important to note that three versions of the application have different song playback durations (up to 4 minutes).

While creating media products using Suno and their application in practical training, the students found that these generated educational products are highly effective tools for increasing students' motivation to study classic poetic works by renowned poets. Rendering poems in song form aids in better memorization of the text, enriching the active vocabulary. Rhyming becomes more appealing to students, encouraging creative imagination and promoting emotional intelligence development. Young students listen to the newly created songs with interest, which enhances their auditory perception and enriches their aesthetic experience. Suno can also be used to organize audio quizzes, which will help better assimilate literary material.

When creating audio content with Suno AI, it is essential to accurately formulate the desired plot and keywords for generating the song lyrics based on the specified parameters (up to 3000 characters). The program randomly generates the lyrics for future songs. After completing the lyrics creation, the user must select the music style from the list: alternative/indie, strong beat, catchy, emotional, energy,

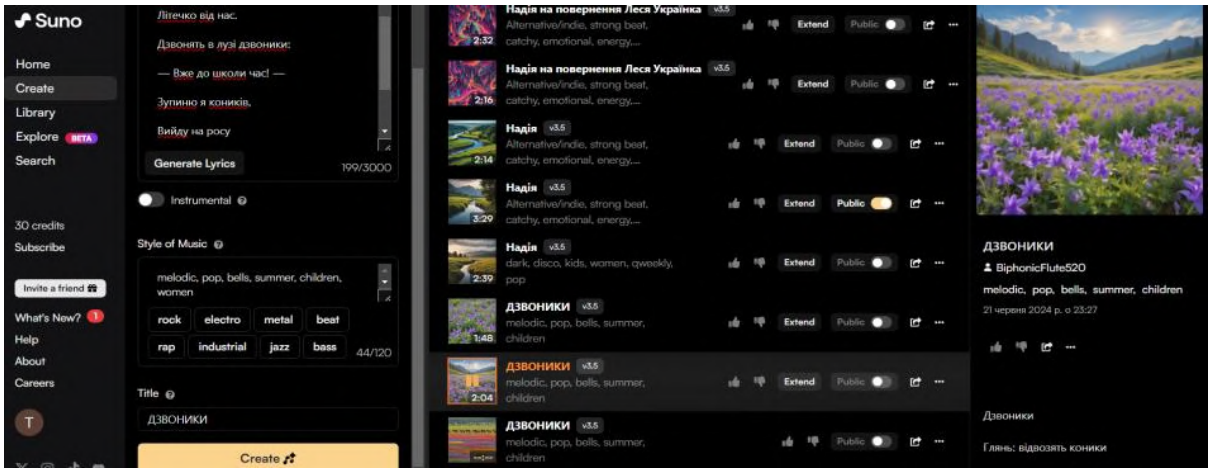


Figure 1: An example of song generation in the Suno program.

dramatic, pop, electro, guitar, etc. The option is to display only the musical accompaniment without lyrics by choosing “Instrumental”. This function can help organize quizzes where students recreate the song/poem lyrics according to the provided musical accompaniment. The final step in creating the music is formulating a title, entering it in the corresponding field, and saving it. The generated content can be downloaded, copied via a link, and shared within the program’s user system.

Thus, creating literary-musical content using the analyzed AI tool helps to creatively present poetic works that may initially seem challenging to understand. The moods and emotions of a lyrical work conveyed through music enhance the comprehension of primary school students. Suno AI uses advanced artificial intelligence algorithms to analyze musical structures and chord progressions, allowing users to generate songs quickly. The free version has a limit of five songs per day. For more songs, paid versions – Pro Plan and Premier Plan – are required.

The main advantages of Suno AI are:

- easy and quick song creation based on the specified style;
- the system creates two unique melodies for each song, allowing the user to choose;
- usage is facilitated by the daily distribution of free credits for song creation, enabling users to continually update their content;
- the ability to download finished songs and share them on social media platforms.

A similar tool is the Udio program (https://www.udio.com/), which also focuses on creating songs. Notably, the program is aimed at creating original content. Compared to the previous AI tool, Udio offers fewer features for users who have a free version. The song lyrics can contain up to 350 characters, and the audio playback lasts up to 32 seconds. It is possible to save the file in mp3 format, and users get 10 credits per day with an additional 100 credits per month. Remixes can also be made. The paid versions (Standard, Pro) offer more features, such as creating songs up to 15 minutes long, downloading files in MP3 and WAV formats, and uploading videos.

Udio is useful for teachers who seek variety in song narration, as it allows for the use of backing vocals and has a more extensive list of playback styles compared to Suno. Regarding the interface, it is more complex than that of Suno. To create a track, users must register in the system, enter the song lyrics into a particular field, define style tags, choose the performers’ gender, etc. There is also an option for automatic song creation. A distinctive feature of Udio is its expanded functionality, including quality determination and clip start. The song creation process takes up to 2 minutes. Udio offers advanced music styling options. However, the free version has limited usage capabilities. Udio stands out for its stable audio quality without distortions, making it attractive to those who value technical precision in music. Udio allows users to create musical intros and outros and generate album covers. Udio can “hallucinate” vocal parts by entering characters and creating unique and experimental vocal

performances. Compositions in Udio are limited to 30 seconds, requiring extensions for full-length songs, which can complicate the song creation process. The paid versions can change the track length after creating a trial version.

Suno is suitable for creating experimental music and background accompaniment for media, while Udio specializes more in traditional genres such as pop, rock, and video music. Both platforms have great potential for creating soundtracks for games and movies, allowing a wide range of users to create high-quality music. Suno AI and Udio are two powerful AI music-creation tools with unique advantages and features. For use in primaryschool lessons, generative products from these programs can be implemented. They diversify the sound of poems in songs, chosen according to the curriculum for young students.

Boomy (https://boomy.com/) offers more musical accompaniment options. The program's main idea is to create songs in various musical styles and add custom or generated vocals. Boomy differs from previous tools by allowing composition editing during the creation process. Users can create up to 25 songs. During the song creation, the author can recite a poet's poem or create their own lyrics, entering them as a prompt for vocal accompaniment.

Boomy's distinguishing feature is its six basic styles: nature sounds, electronic music, rap beats, relaxing beats, meditation, and calm music. Users can also create and combine styles based on specified prompts. The number of vocal characters in the free version is up to 255. Users can use an audio recording, text-to-speech, or auto-generation for vocals. There is an option to edit the generated product and download it in MP3 and WAV formats (paid versions required). The main advantage of Boomy is the ability to edit content throughout the song creation process.

The suggested programs are engaging, helpful, and effective for preparing primary school teachers to work in new conditions of informatization and digitalization. AI programs will help future teachers create high-quality and unique multimedia educational products, integrating them into the primary school educational process. Creating songs based on poems facilitates their perception and memorization, which is a positive aspect of educational activities. The features of each music-generating program are presented in table 1.

Table 1: Analysis of artificial intelligence programs for the generation of literary and musical content.

Application criteria	Suno	Udio	Boomy
Interface	Intuitive, easy to use	More complex, with extended functionality	Intuitive, the ability to edit the song during creation
Creating a song	Up to 1 minute	Up to 2 minutes	Up to 2 minutes
Maximum song duration	Up to 4 minutes in version 3.5	Up to 15 minutes in paid versions	Possibility of increase from 30 seconds
Musical styles	Alternative/indie, strong beat, catchy, emotional, energy, dramatic, pop, electro, guitar, others (up to 120 characters for style selection)	Various styles including pop, rock, music for film and television	Nature, electronic music, rap beats, relaxing beats, meditation music, the possibility of combining styles according to the specified prompts
Using audio	Ability to download an audio/video clip to create a song	Ability to download video, audio recording	The ability to read a poem in your own voice or use automatic vocal creation

Continued on next page

Table 1 – continued from previous page

Application criteria	Suno	Udio	Boomy
Paid versions	Pro Plan and Premier Plan with additional features	Standard, Pro with additional features (up to 15 minutes of songs, downloading files in mp3 and WAV formats)	Paid versions with additional features such as saving in mp3 and WAV formats
Free credits	50 credits per day (up to 5 songs)	10 credits per day with an additional 100 credits per month	Ability to create 25 songs in the free version
Copyright infringement	No, the impossibility of selecting a text by a specific artist and copying its timbre or melodies	No copying the tone or melodies of famous artists, but can create original content	The ability to add your own or generated vocals, the ability to remove music fragments during editing
Organization of audio quizzes	There is an opportunity to create audio quizzes for better learning of the material	Ability to create music intros and endings, as well as generate album covers	Ability to create musical introductions and final parts, generate album covers
Use in the educational process	Suitable for creating literary and artistic content for literary reading lessons in primary school. The multimedia product created by the teacher helps students to better remember the text and develop auditory perception, develops the emotional intelligence of younger students	More suitable for the creation of traditional genres such as pop, rock and music for the musical accompaniment of poems, i.e. background playback of the author's music	Suitable for creating experimental music and background music for media, also useful for teachers who want variety in singing poetry-based songs
Unique opportunities	Generation of two unique melodies of the same song at the user's choice	Creation of various musical styles and their clear reproduction	The possibility of editing the composition during its creation, creation of 25 songs, the possibility of automatic creation of a song with the use of backing vocals
User support	Constantly updated content thanks to daily free credits	Access to advanced functions in paid versions, the possibility of creating author's content	Support for users in creating and editing songs, the ability to create their own audio and edit compositions during their creation

Literary content can be reproduced not only with musical accompaniment but also through visualization. As an alternative, students were suggested to use visualization tools. In preparation for reading lessons, future teachers could generate assignments to study stories, fairy tales, poems by classic authors, or works for children by contemporary writers. Using artificial intelligence programs, they tried to create dialogues between characters and narrations by a character about the content of a fairy tale. They posed questions on behalf of the main characters to organize a discussion about the content of the work. They found that tasks for students could also be prepared as audio messages. Assignments could be created in the form of characters' narrations about events from the fairy tale or questions from the main characters to students regarding the content of the works. Additionally, video

characters can develop and stimulate conversations with young students.

Students were offered to test platforms like Pictory, Lumen5, and InVideo AI for creating videos using AI tools. The products of the Pictory platform (https://pictory.ai/?el=2000&htrafficsource=pictoryblog) can be used as dynamic and visual aids for primary school students. When working on various literary works, it is essential to motivate young students to engage in reading activities, arouse their interest in the content, and foster their desire to learn more about the authors. With Pictory, it is possible to create visually appealing videos with the necessary content. A difficulty in using the program was that video-generated prompts could only be given in English. However, adding text in any language over the video is an option. Additionally, music, voice-over,subtitles, AI-generated images, effects, emojis, and more can be added. This variety of features makes the platform convenient for use in the educational field.

To start working on the platform, register and choose the educational content option "Script to Video". In this window, you will find educational videos. For video generation, text customization in English is required, dividing it into scenes and using keywords to help form the scenes (visual representation of the desired content in video format). To do this, highlight the text that reveals the essence of the video content using the "Highlight" button on the left side panel. The program will automatically break the text into scenes and generate the video. Then, you can edit the text: change the design, add animations, background music, and voice-over recorded by yourself. There is a unique navigation panel under the video for editing. You can change or delete the scene order and adjust the voice- over volume. After creating the video, click the "Download" button to save it as a project in the app's library or MP4 format to the desired resource. The video duration is about 20 minutes and is managed by the video author. The trial version (video creation and storage) is available for free for 12 days.

As a result of AI generation, you can create a high-quality, dynamic educational product. Pictory is quite versatile, dynamic, and suitable for lessons to optimize literary works' perception. With the app, you can read a story with corresponding visuals, create dialogues between story characters, and record AI-generated voiceovers. However, this feature is only available in English. Therefore, you can make recordings with students or use other apps for voiceover recordings. The program is beneficial for reading poems, as the visual perception of dynamic videos can capture children's attention to poetry and create visual images for easier memorization of literary works. The video is created in a few minutes, and the platform contains over 15,000 ready-made templates that can be used, helping primary school teachers quickly make the necessary educational content without special video editing skills.

For example, to engage young students' attention to work and their reading interests, students were asked to create a photo collage based on the fairy tale "Kotygoroshko". The creation algorithm is as follows: prepare the text according to the content of the fairy tale; choose or add pictures that correspond to its content; add a musical background; or make an audio recording of the narrator (figure 2).

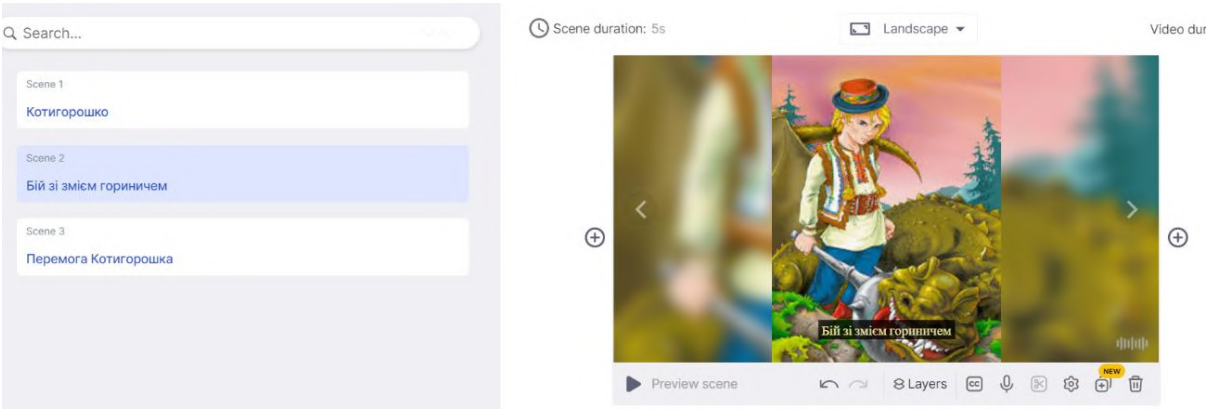


Figure 2: An example of the generation of the tale "Kotygoroshko" in the Pictory program.

Lumen5 (https://lumen5.com/) proved to be an exciting and convenient tool for creating bright, dynamic, interactive content. It has several key advantages: automated video creation, where the

platform analyzes the text and generates corresponding video clips with graphics, photos, and music; a significant number of templates for using and customizing various colors, fonts, and other elements for text display; and integration of various content sources (articles, blogs, RSS feeds), allowing for quick video creation based on existing content.

Lumen5 is a valuable tool for educators looking to effectively transform their textual content into attractive video clips for teaching and focusing students' attention on literary material. To create literary content, a teacher can upload a writer's or poet's biography, generate interesting videos about them, and place the text of poems, fairy tales, and stories to be displayed in the video. This educational product is valuable because students perceive it through different senses, allowing them to read, listen, and watch. The versatility of content delivery by this neural network makes it extremely attractive for use in the educational process.

The advantages of using Lumen5 in an educational context include:

- the ability to create multimedia presentations and videos helps visualize complex topics;
- it can be used during distance learning to present theoretical information in an animated form;
- the automation of creating high-quality visual materials reduces the teacher's preparation time for lessons.

To use the Lumen5 platform, you need to register. Then click the "Create Video" button on the main page. Choose from the available templates to create a video. Enter text or paste a link to an article, blog, or other source to be converted into a video. Lumen5 will automatically analyze the text and suggest appropriate segments for the video. Distribute the text across different scenes, editing each one, adding or removing text, changing its position, etc. You can also add and change images, video clips, and graphics for each scene using the navigation panel on the left. You can use the built-in media library or upload your own files. Customize colors, fonts, and other design elements according to personal preferences. Choose a music track from the Lumen5 library to add audio to the video or upload your own music. A video preview is available before downloading, allowing you to choose different formats and resolutions depending on your needs and preferences. To save and download the video, simply click the "Publish" button.

A similar program in functionality is InVideo AI (https://ai.invideo.io). This program quickly creates videos based on the text and information provided for analysis. The difference with InVideo AI is the ability to analyze the material specified by the user and create its own text for further video generation. Based on the selected style and target audience, the program voices the text and displays corresponding images and video clips. After generating the video, you can change the scenes and text artificial intelligence suggests. The program is useful for processing interesting facts about the lives of contemporary artists. Educational products created with this program can be used as an interactive tool while studying literary works to demonstrate the story's events. It is alsouseful for visualizing the images of the main characters, helping students reveal their characters and express their own views on the situations the characters find themselves in. In this program, you can add any audio file or use the built-in sound effects and music library. With the program, you can create virtual tours of places related to the work. For example, you can generate video content with information about a famous writer in both contemporary and classical interpretations. Students completed assignments to create video content about T. Shevchenko (figure 3). The advantage of the finished media product is that a lot of information was quickly analyzed, and the most interesting fragments related to the poet were selected and combined into a slideshow. This includes important biographical information, works, and paintings by the artist, as well as images on currency notes.

To generate a video, you need to write a script or plan for the voice-over, upload the audio or photos you want to use in the video and choose a provided template. You can also use AI-generated video based on the user's script and the provided information about the desired video content. The program analyzes the content and creates the video, which can be edited. If the high-quality educational product meets the user's needs, the video can be downloaded and shared on social networks.

Let's note that Pictory, Lumen5, and InVideo AI programs offer free trial versions, making them accessible for use in preparing primary school teachers. These tools can be employed to create modern,

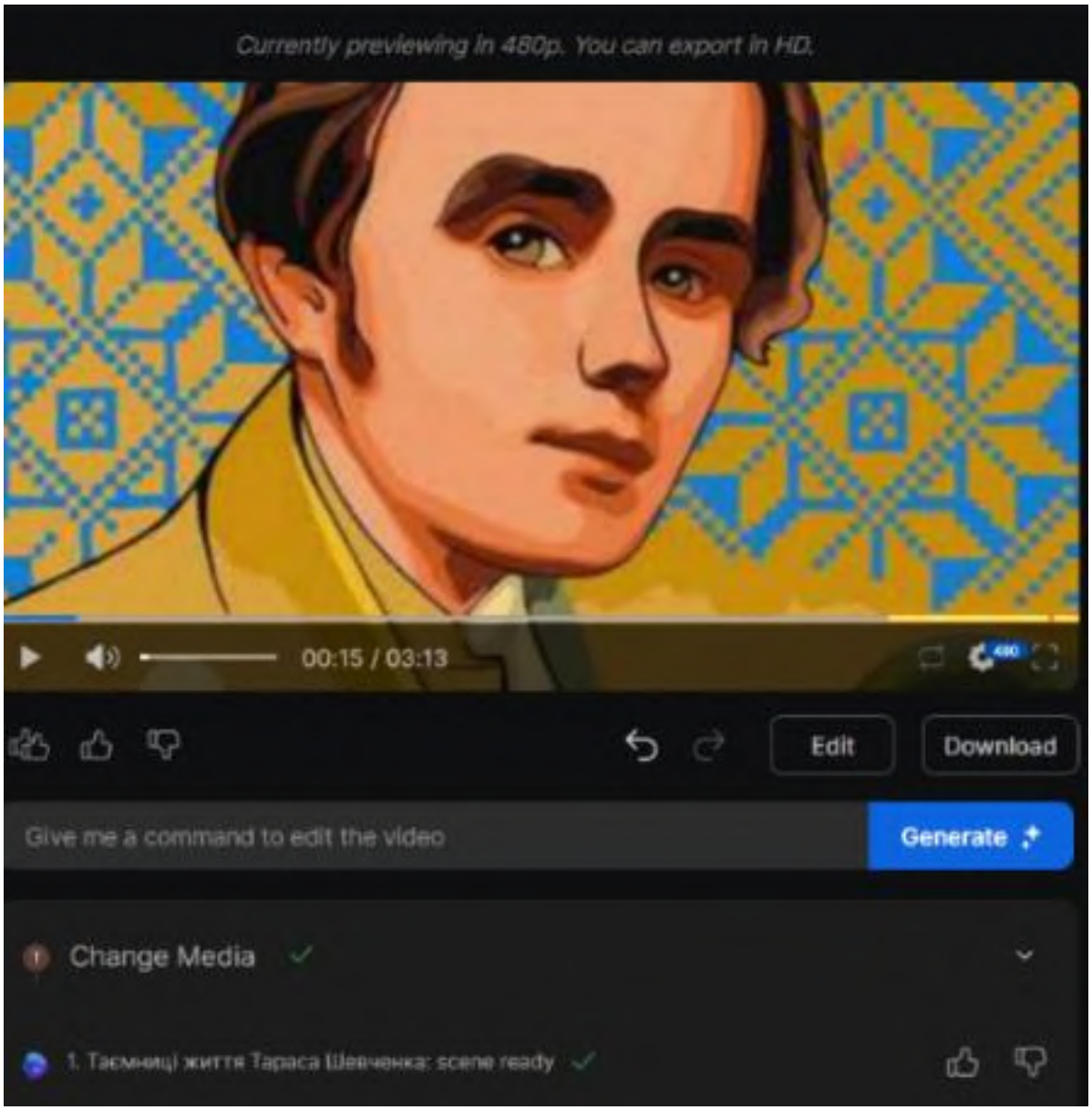


Figure 3: An example of generating a biography of T. Shevchenko in the InVideo AI program.

interactive didactic resources aimed at enhancing reading activities and fostering reading interests among young students. Table 2 presents the features of each video-generating program.

4. Discussion

The results of this study demonstrate the potential of using AI tools for generating literary-artistic content in preparing primary school teachers for professional activities. The findings highlight the importance of integrating AI technologies into teacher education programs to foster the development of digital literacy skills, promote innovative teaching methods, and cultivate a mindset of continuous learning and adaptation.

The survey results reveal that while most students are generally aware of AI technologies, they require further knowledge and training to effectively apply AI tools in their future classrooms. This underscores the need for comprehensive AI competency development in teacher preparation programs. By engaging pre-service teachers in hands-on experiences with AI tools, such as creating multimedia

Table 2
Analysis of artificial intelligence programs for generating videos with literary content.

Criterion	Pictory	Lumen5	InVideo AI
Functional	Visual interactive stories	Transform text into video	Video editing using artificial intelligence
Using	Create and share story pages	Convert written content to video	Create professional videos quickly and easily
Advantages	Dynamic and visually appealing videos, the ability to create videos from scratch, integration with various content sources	Automated video creation, the possibility of creating multimedia presentations, the possibility of use during distance learning	Quick video creation, the ability to create interactive content, the ability to voice the text in Ukrainian
Disadvantages	English language interface, limited video duration in the trial version	English language interface, limited video duration in the trial version	Paid, English interface, inability to create your own text, only edit and delete
Cost	Free trial, paid plans	Free and paid versions	Free version and paid plans

didactic tools based on literary material, we can enhance their confidence and proficiency in leveraging these technologies for educational purposes.

The advantages of using AI tools for generating literary-artistic content, as identified by the participants, include the ability to create engaging and interactive learning experiences, facilitate personalized learning, and support the development of students' creativity and critical thinking skills. However, the study also reveals potential challenges and limitations, such as the need for careful curation and validation of AI-generated content, the importance of providing adequate technical support and resources, and the necessity of addressing ethical concerns.

The integration of AI technologies in educational settings raises critical ethical considerations that must be addressed to ensure responsible and beneficial implementation. This study proposes several measures to mitigate potential risks, including:

- ensuring the accuracy and appropriateness of AI-generated content through rigorous content validation processes and teacher training;
- promoting responsible and transparent use of AI technologies by developing clear policies, providing transparency about AI usage, and fostering open dialogue among stakeholders.

5. Conclusions and prospects for further research

The modern generation of students requires new approaches to learning and presenting educational material. Therefore, the proposed tasks of generating literary-artistic content for primary school are useful and practical for preparing future teachers for professional activities in the context of informatization.

The integration of AI tools for generating literary-artistic content in primary school teacher preparation has significant implications for sustainable education practices. By developing pre-service teachers' digital literacy skills, promoting innovative teaching methods, and fostering a culture of continuous learning and adaptation, this approach contributes to the long-term sustainability of education in the face of rapid technological advancements.

The described capabilities of artificial intelligence programs confirm the importance of using instrumental music services in teaching practice to create literary-artistic content for literature reading lessons. Each of the analyzed AI programs diversifies the study of poetry for children, gives a new sound to poetic works, and helps deeply feel and explore the moods and emotions conveyed by the authors. Young students perceive poetic works with greater interest and attention when accompanied by music. We are confident that the AI programs analyzed by the authors of this article will help future teachers develop innovative multimedia products to ensure the realization of literary education tasks in

primary school. Through detailed testing of AI programs, we highlight their advantages in creating literary-artistic content for young students. In the Suno program, the undeniable advantages are the free version, simplicity and ease of use, increased text length for poems, and fast song creation. The Udio program contains the original content of the developers and more options for musical compositions. The Boomy program allows you to record your audio and use it to create songs.

By analyzing the specifics of using Pictory, Lumen5, and InVideo AI, it is worth emphasizing their capabilities to significantly increase students' interest in perceivinggenerated educational material and activating reading activities. These AI programs allow for creating visually appealing and engaging content that attracts students' attention, motivates them to study the material, facilitates perception, and aids in quickly memorizing educational material. This includes the visual representation of writers' biographies and visualization of characters, events, and plots. Such educational products are valuable because students perceive them through different senses, enabling them to read, listen, and watch.

As AI technologies continue to evolve, it is crucial for teacher education programs to embrace these tools and equip future educators with the competencies needed to harness their potential effectively. By doing so, we can ensure that the next generation of primary school teachers is well-prepared to navigate the challenges and opportunities presented by the digital age, ultimately promoting sustainable education practices that benefit learners, educators, and society as a whole.

It is undoubtedly necessary to continue researching the directions of using artificial intelligence in the professional activities of primary school teachers, developing methods for applying AI-generated content in various areas of primary education, and for the professional development of future educators.

Author Contributions: Conceptualization and methodology, Svitlana P. Palamar and Serhiy O. Semerikov; investigation, writing – review & editing, Svitlana P. Palamar, Liudmyla L. Nezhyva, Nataliia O. Semenii and Serhiy O. Semerikov; data curation, Svitlana P. Palamar, Liudmyla L. Nezhyva and Serhiy O. Semerikov; formal analysis, Svitlana P. Palamar and Liudmyla L. Nezhyva; writing – original draft, Svitlana P. Palamar, Liudmyla L. Nezhyva and Nataliia O. Semenii; visualization, supervision, project administration, Svitlana P. Palamar; validation, resources, Serhiy O. Semerikov. All authors have read and agreed to the published version of the manuscript.

Declaration on Generative AI: During the preparation of this work, the authors used Claude 3.5 Sonnet in order to: Improve writing style. Further, the authors used Grammarly in order to: Grammar and spelling check. After using these tools, the authors reviewed and edited the content as needed and takes full responsibility for the publication's content.

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Social media as a tool for career guidance in higher education

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Abstract

Social media has revolutionised the landscape of career guidance in higher education, affording unprecedented opportunities for students, educators, and career advisers to connect, share insights, and access real-time professional development resources. This article explores the transformative impact of social media on career guidance practices, with a particular focus on its role in delivering personalised support, facilitating networking with industry professionals, and exposing students to diverse career paths through interactive platforms. The methodology section outlines a systematic approach to leveraging social media for effective career guidance, incorporating a three-tiered system of engagement, monitoring, and evaluation. An experimental study investigates the effectiveness of implementing social media-based career guidance under specific pedagogical conditions. The results confirm the hypothesis that social media can significantly enhance career guidance outcomes when supported by appropriate strategies and frameworks. This research highlights the potential of social media as a powerful tool for empowering students in their career development journey and underscores the importance of integrating digital technologies into modern career guidance practices.

Keywords

social media, career guidance, higher education, professional development, networking, digital technologies, pedagogical conditions, student empowerment

CEUR-WS.org/Vol-3918/paper321.pdf

1. Introduction

Social media has revolutionised career guidance in higher education, offering unprecedented opportunities for students, educators, and career counsellors to connect, share insights, and access real-time professional development resources. This digital transformation enables universities to deliver personalised career support, facilitate networking with industry professionals, and provide students with valuable exposure to diverse career paths through interactive platforms.

The transformation of social networks from mere communication tools into educational resources has been remarkable over the past two decades. During the post-COVID era, social media has become increasingly prominent in higher education, with educators and students utilising these platforms not only for information gathering but also for focused educational purposes.

According to the Digital 2021: Global Overview Report, 4.2 billion people worldwide – approximately half of the global population – use social networks for business, news, marketing, or education [1].

AREdu 2024: 7th International Workshop on Augmented Reality in Education, May 14, 2024, Kryvyi Rih, Ukraine
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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

Social media platforms serve as Internet resources populated by society, including Wikipedia, YouTube, Facebook, and others. The fundamental concept behind social media is based on Web 2.0, where content creation isn't limited to site owners but is open to all users [2].

Kaplan and Haenlein [3] provide a definition of social media as Internet-based applications built on Web 2.0's ideological and technological foundations, enabling user-generated content and exchange (table 1). This content encompasses text, video, images, podcasts, and various multimedia communications, with prominent examples including Facebook, Twitter (X), LinkedIn, Google+, and messaging platforms [3].

Table 1
Traditional vs modern career guidance approaches in higher education.

Traditional approaches	Modern approaches
Outdoor advertising	University website communication
Media advertising (radio, newspapers, TV)	Social media engagement
Open days for prospective students	Messenger communication
Roundtables, open lectures	Online job portal presence
Participation in city events	Open access Internet materials
Direct sales	Alumni network testimonials

Career guidance history traces back to France and Belgium in the late 19th and early 20th centuries. However, concepts of professional-personal compatibility existed even in ancient times, with Plato emphasising the importance of matching natural abilities to work roles [4].

The modern understanding of career guidance emerged during the rapid industrial development of the late 19th century. Parsons [5], established three crucial factors for career choice: self-understanding of abilities and limitations, knowledge of job requirements and conditions, and rational correlation between these factors [5].

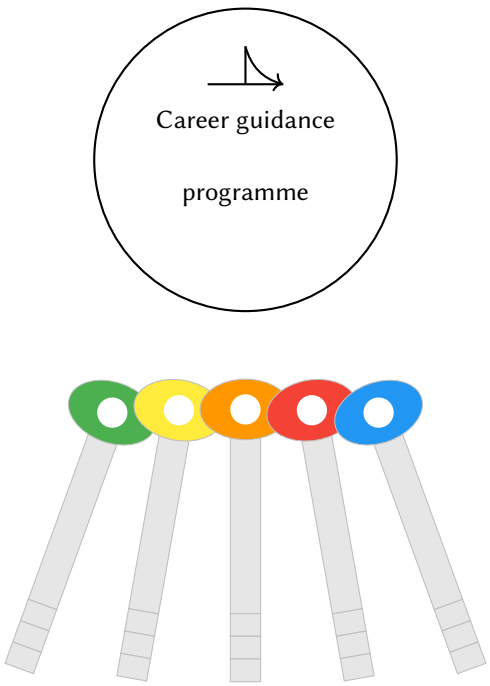
Contemporary career guidance incorporates both traditional and innovative approaches through social media platforms. These digital tools provide several advantages: accessibility to career information, qualification requirements, salary levels, and development opportunities (table 2). Mobile applications offer convenience for students to access guidance resources anywhere, anytime, while video and webinar formats enable online consultations and training sessions [6].

Table 2
Benefits of implementing digital career guidance.

Benefit category	Impact
Academic performance	Improved grades and test scores
Career readiness	Enhanced career planning skills
Social development	Better interpersonal relationships
Personal growth	Increased self-awareness
Technology integration	Improved digital literacy
Educational access	Wider reach to resources

Holland [7] suggests that individuals seek environments where they can utilise their skills and express their attitudes and values. This approach emphasises that people are attracted to professions matching their personal characteristics and contextual factors [7]. The accuracy of self-knowledge and career information serves as crucial prerequisites for career decision-making [8].

Modern career guidance programmes should prepare individuals for constant workplace changes (figure 1). The career decision-making process includes five interconnected phases: initiation, exploration, decision-making, preparation, and implementation [9]. These aspects focus on establishing effective counselling relationships, determining current career planning motivation, and making career planning relevant to students' lives.



Comprehensive development

Focuses on holistic growth, integrating various skills and knowledge areas.

Lifelong learning

Encourages continuous education and skill enhancement throughout life.

Individual needs recognition

Tailors guidance to meet the unique requirements of each individual.

Practical skills integration

Emphasizes the importance of applying theoretical knowledge in real-world scenarios.

Technology implementation

Incorporates modern technological tools to enhance career guidance.

Figure 1: Career guidance programme principles.

Yermolayeva [10] examines how social networks can be used as a modern tool in career guidance counseling, specifically focused on future applicants in the information sector.

Latifah et al. [11] noted that career guidance counsellors must be technologically competent, particularly in implementing social media in today's digital era. Social media serves as a support tool for career guidance services. This study examines stages of career guidance using social media through literature analysis of national and international journals. School career guidance introduces opportunities, identifies interests, aids decision-making, and facilitates workplace adaptation. Social media functions as an unlimited information field for students' social interaction and targeted information delivery. Career guidance requires active counsellor involvement. The critical aspect is helping students establish themselves and make meaningful career decisions. Counsellors can implement social media as interactive tools in school career guidance services [12].

Alim [13] shows that UAE youth feel underprepared for work, indicating a need for improved career guidance. While social media offers expanded opportunities for career guidance delivery, UAE universities primarily utilize online career planning systems rather than interactive social media platforms. This limitation stems from content moderation pressures and strict UAE privacy laws governing social media use. For effective integration of social media in career guidance, universities must first understand students' preferences regarding delivery methods [13].

Social media platforms and mobile learning technologies enable continuous career guidance and professional development, making educational resources accessible anytime and anywhere [14, 15].

Social media platforms serve as effective channels for delivering career guidance content and facilitating professional networking among students and potential employers [16].

The implementation of automated systems and social media tools creates an integrated environment for effective career guidance and professional development tracking in higher education [17].

Integration of social media with career guidance tools creates an interactive environment that significantly enhances student engagement in career exploration and decision-making [18].

The contemporary Ukrainian approach defines career guidance as a system of scientifically-based pedagogical measures aimed at preparing young people for career choices, emphasising the crucial role

of personal characteristics, interests, and abilities in this process [19].

2. Methodology of using social media for career guidance of professional pre-higher education students

Social media platforms have become instrumental tools in modern career guidance practices, offering unprecedented opportunities for educational institutions to connect with and guide students through their professional development journey. This methodology section explores the systematic approach to leveraging social media platforms for effective career guidance of students in professional pre-higher education programmes.

The integration of social media into career guidance represents a paradigm shift from traditional counselling methods to a more dynamic, interactive approach. This methodology builds upon the Social Career Cognitive Theory, which emphasises the role of self-efficacy, outcome expectations, and personal goals in career development. When applied to social media, this theoretical framework provides a structure for understanding how digital interactions can influence career choices and professional identity formation (figure 2).

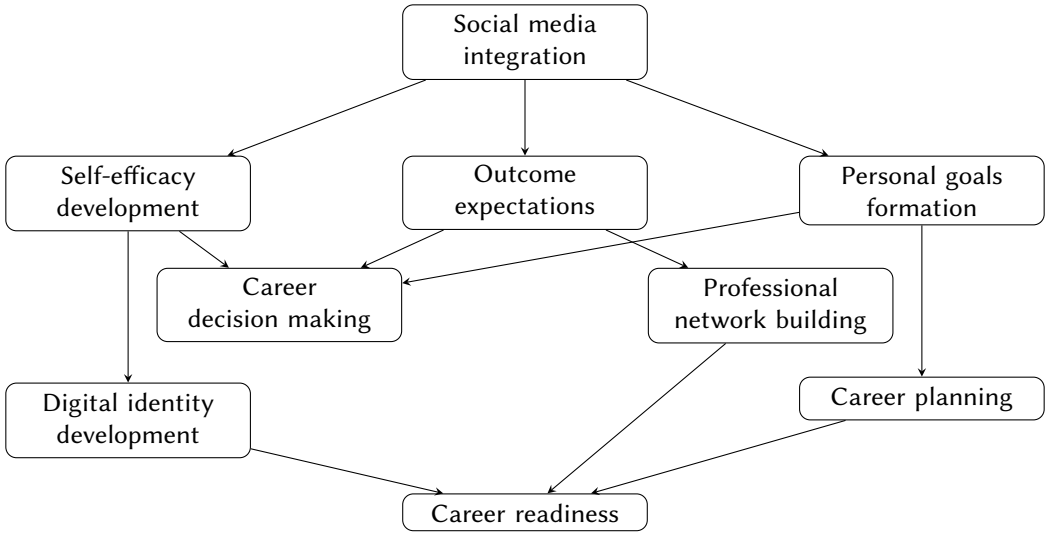


Figure 2: Social media career guidance theoretical framework.

The implementation of social media for career guidance follows a structured approach that encompasses multiple platforms and engagement strategies (figure 3). The methodology employs a three-tiered system of engagement, monitoring, and evaluation to ensure effective career guidance delivery.

Implementation steps of methodology of using social media for career guidance of professional pre-higher education students is shown in figure 4:

The methodology focuses on creating an interactive, informative environment where students can explore career options, connect with professionals, and receive personalized guidance through social media platforms.

The selection of appropriate social media platforms is crucial for effective career guidance. Each platform serves distinct purposes and reaches different audience segments. The methodology incorporates a comprehensive content strategy tailored to each platform's unique characteristics and user behaviour patterns.

The bar chart visualisation presents a comparative analysis of four major social media platforms (LinkedIn, Instagram, Facebook, and Twitter (X)) across three crucial performance indicators (figure 5).

The engagement rate, represented by purple bars, demonstrates the percentage of active interaction with career guidance content. LinkedIn leads with a 5.2% engagement rate, followed closely by Instagram at 4.8%. Facebook shows a moderate engagement rate of 3.9%, while Twitter (X) demonstrates the lowest

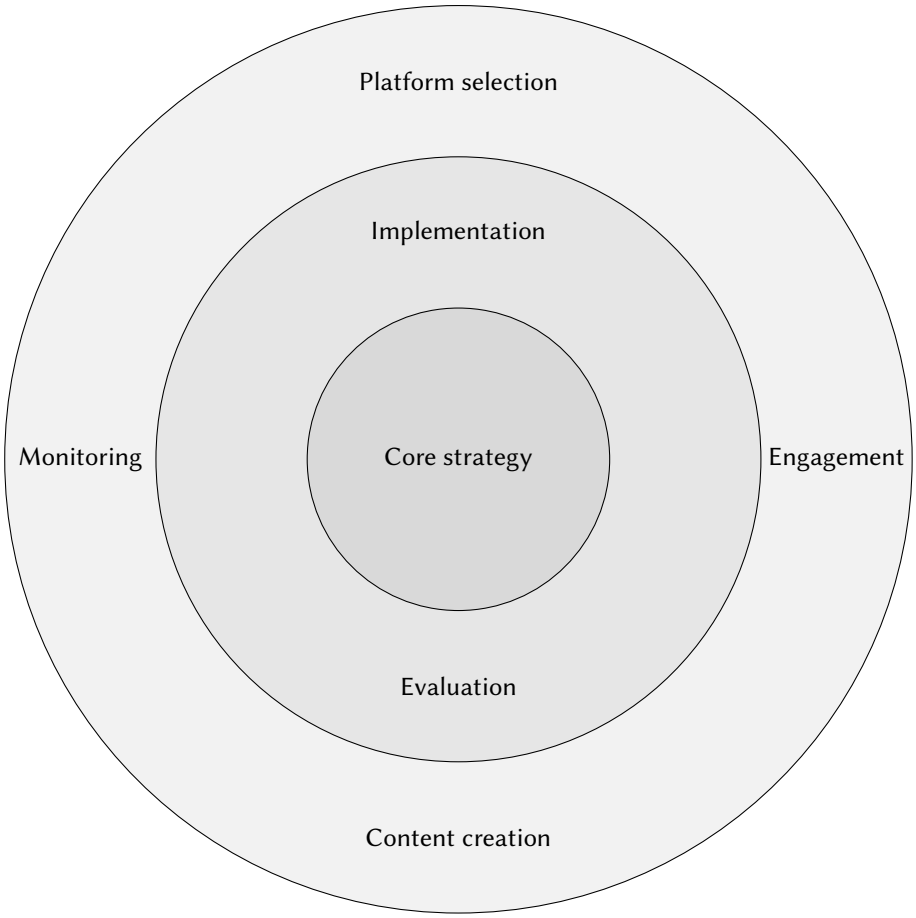


Figure 3: Social media implementation strategy.

engagement at 2.7%. This pattern suggests that professional-oriented platforms like LinkedIn generate more meaningful career-related interactions.

Career outcomes, depicted by green bars, reflect the percentage of successful career-related results achieved through each platform. LinkedIn again demonstrates superior performance with 68% positive career outcomes, while Facebook follows with 52%. Instagram achieves 45% career outcomes, and Twitter (X) shows 31%. This metric encompasses various successes such as job placements, internship securing, and professional networking achievements.

Student adoption, shown in yellow bars, indicates the percentage of students actively using each platform for career development purposes. Instagram leads this metric with 89% adoption, followed by Facebook at 82% and LinkedIn at 75%. Twitter (X) shows the lowest adoption rate at 58%. This reveals an interesting dynamic where platforms with higher student adoption don't necessarily correlate with better career outcomes.

The methodology incorporates various engagement mechanisms designed to facilitate meaningful interactions between career guidance professionals and students. These mechanisms are structured to promote both passive and active engagement, ensuring comprehensive career support. Content delivery follows a carefully planned schedule that aligns with the academic calendar and key career decision points. The methodology establishes optimal posting times and frequencies based on platform analytics and student engagement patterns.

The effectiveness of social media-based career guidance is continuously monitored through various metrics and evaluation methods. This systematic approach ensures that the methodology remains responsive to student needs and adapts to changing career landscape requirements.

Performance trends analysis (figure 6), the line graph visualisation tracks three key performance indicators over an academic year from September to April, showing the evolution of career guidance

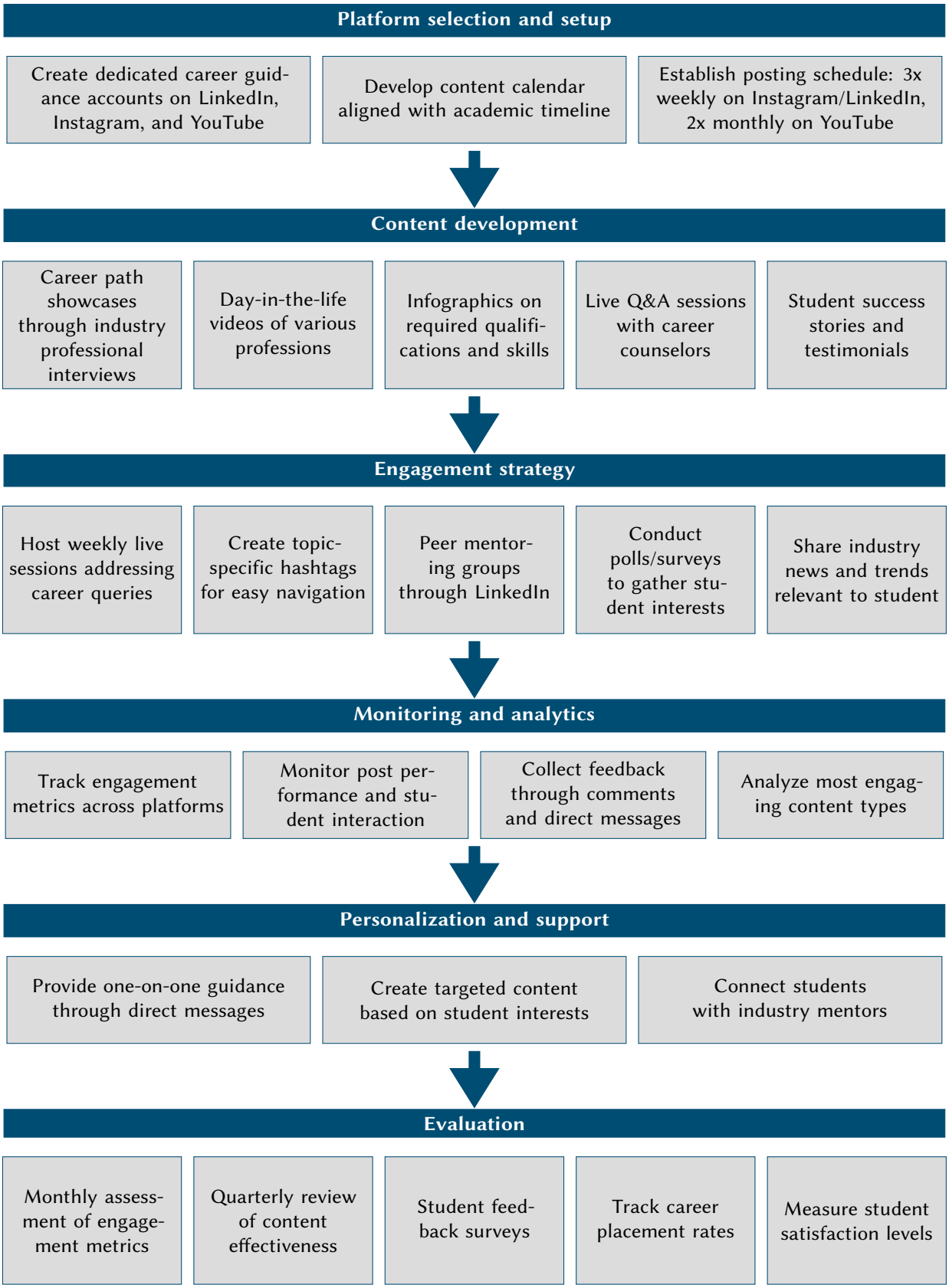


Figure 4: Implementation steps of methodology of using social media.

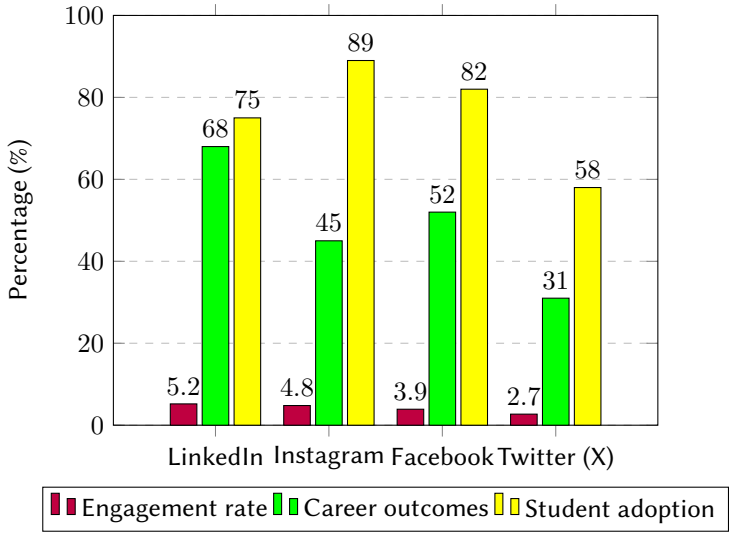


Figure 5: Platform performance metrics.

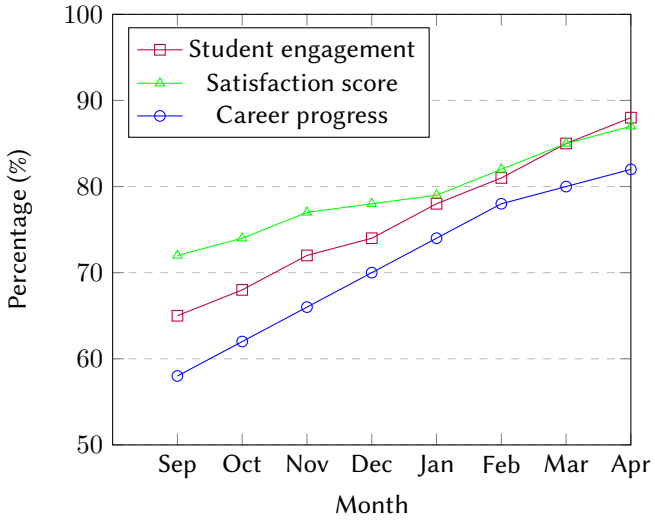


Figure 6: Performance trends analysis.

effectiveness.

Student engagement (purple line) demonstrates a steady upward trajectory, beginning at 65% in September and reaching 88% by April. This considerable increase of 23 percentage points suggests growing student participation in social media-based career guidance activities throughout the academic year. The steepest increase occurs between January and March, coinciding with typical internship and job search periods.

Satisfaction sScore (green line) begins at 72% in September and rises to 87% by April, showing a 15 percentage point improvement. The trend line shows consistent growth with slight plateaus during December and January, possibly corresponding to holiday periods. The steady increase suggests continuous refinement and improvement of career guidance strategies based on student feedback.

Career progress (blue line) starts at 58% in September and reaches 82% by April, showing the most significant overall growth of 24 percentage points. The metric demonstrates a consistent upward trend, with particularly strong growth between November and January. This period typically aligns with students' career planning and goal-setting activities for the new year.

The intersection of these metrics reveals several key insights:

1. All three metrics show positive growth throughout the academic year, indicating successful implementation of the career guidance strategy.
2. The narrowing gap between all three lines towards April suggests increasing alignment between engagement, satisfaction, and actual career progress.
3. The consistent upward trajectory across all metrics, without significant downturns, indicates sustainable and well-managed programme implementation.
4. The parallel growth patterns suggest successful coordination between different aspects of the career guidance programme, where improvements in engagement translate to better satisfaction and career progress.

These visualisations effectively demonstrate both the immediate impact of platform selection and the long-term effectiveness of the career guidance methodology. The data supports the strategic emphasis on LinkedIn for professional outcomes while maintaining strong presence across platforms to maximise student reach and engagement.

The methodology incorporates comprehensive impact assessment mechanisms to evaluate the effectiveness of social media-based career guidance. This assessment focuses on both quantitative metrics and qualitative feedback from students, employers, and educational institutions.

The impact assessment framework considers multiple dimensions of career guidance success, including student engagement levels, career decision-making confidence, and eventual employment outcomes. Through continuous monitoring and evaluation, the methodology enables evidence-based refinement of career guidance strategies.

The methodology remains flexible and adaptable to accommodate emerging social media platforms and evolving career guidance needs. Regular reviews and updates ensure that the approach remains relevant and effective in supporting students' career development journey. The structured approach, combined with continuous monitoring and evaluation, provides a robust framework for implementing effective career guidance strategies through social media platforms.

3. Experimental study

The aim of our research and experimental work is to confirm the hypothesis that career guidance for students of pre-higher education via social media will be more effective under certain pedagogical conditions:

1. Motivation for independent analysis of existing professions using social media.
2. Familiarising applicants with existing online job search tools.
3. Promoting social media specialties using the example of Instagram.

At each stage of the pedagogical experiment, a set of pedagogical research methods were used, including theoretical analysis of scientific sources and psychological-pedagogical literature, study and generalisation of the experience of university teachers, as well as observations, interviews, and questionnaires (table 3).

The research and experimental work was carried out at the Kryvyi Rih National University. First-year students majoring in Computer Science were involved in the experiment. We conducted a parallel experiment where the first part of group (10 people) was the control group, and the second part (11 people) was the experimental group.

The pedagogical experiment consisted of two stages: ascertaining and formative. The ascertaining stage aimed to determine the current (general) state of the studied phenomenon and its structural elements. At the stage of the ascertaining experiment, we conducted testing and questionnaires to determine the level of motivation for independent analysis of existing professions using social media, the level of familiarisation of applicants with existing online job search tools, and the level of promoting social media specialties using the example of Instagram.

Table 3
Evaluation criteria, indicators and diagnostic methods for studying the psychological and pedagogical conditions for implementing career guidance in distance learning.

Criteria	Indicators	Diagnostic methods
Motivation for independent analysis of existing professions using social media	1. Desire to learn 2. Desire to use social media to analyse existing professions	1. Learning motivation questionnaire (author's modification) 2. "Applicants motivation to use electronic resources for choosing a profession" questionnaire
Familiarising applicants with existing online job search tools	1. Desire to consciously choose a profession 2. ICT competencies in using web search	1. Questionnaire to determine students' areas of professional preferences 2. ICT competency formation level self-assessment map methodology (authors' modification)
Promoting social media specialties using the example of Instagram	1. Inclination towards a certain type of activity 2. Using social media to search for information about educational institutions and specialties	1. MBTI test (Myers-Briggs Type Indicator – developed based on the works of Carl Jung) 2. "Using social media to search for information about educational institutions and specialties" survey (developed by the authors)

The generalised analysis indicates that most students, according to all criteria, are at the middle level. Regarding the results of the control testing, high indicators are characteristic of only two students (about 10%) in the experimental and control groups. The situation with motivation, the level of ICT competencies, and readiness to use electronic resources is similar: only a limited number of students from both groups have a high level of ICT and electronic resources and are ready to use them. It is noted that a high level of motivation to learn is completely absent. The results obtained indicate that the use of social media for career guidance of applicants in higher education institutions only with the help of conventional distance learning methods complicates the achievement of the effectiveness of the introduction of electronic educational resources and, accordingly, a high level of knowledge, skills and abilities of students.

The formative stage of the pedagogical study was aimed at introducing the developed career guidance for students of professional pre-higher education by tools of social media into the educational process.

After the implementation of our methodology, research was conducted again to identify changes according to the defined criteria. Repeated diagnostics were carried out in the control and experimental groups. The summarised results of the formative and ascertaining stages of the study conducted in the experimental group are shown in table 4.

Comparing the two groups, we see insignificant changes in the control group only according to the criteria "Motivation to use electronic resources" (by 10% high level) and "Use of social media to search for information about educational institutions and specialties" (by 10% medium level), while the experimental group showed positive changes according to all criteria (from 9% to 18.2%).

Summarising the results of the pedagogical study, we can conclude that the verification of the psychological and pedagogical conditions for the introduction of career guidance in the context of distance learning into the educational process of university developed by us is quite effective and it is advisable to use it in practice.

Thus, the results of the experiment confirmed the validity of the hypothesis formulated by us.

4. Conclusions

1. The introduction emphasises social media's revolutionary impact on career guidance in higher education, enabling personalised support, industry networking, and exposure to diverse career paths. The shift from communication to educational resources underscores social media's post-COVID prominence. Kaplan and Haenlein's definition highlights user-generated content, while historical

Table 4
Results of the study of the experimental group at the ascertaining and formative stages of the pedagogical study.

Diagnostic methods	Levels	Ascertaining stage		Formative stage	
		Number	%	Number	%
Motivation for learning activities	High	0	0	1	9.1
	Medium	8	72.7	9	81.8
	Low	3	27.3	1	9.1
Motivation to use electronic resources	High	1	9.1	2	18.2
	Medium	9	81.8	9	81.8
	Low	1	9.1	0	0
Diagnosis of inclination towards a certain professional field	High	4	36.4	6	54.5
	Medium	7	63.6	5	45.5
	Low	0	0	0	0
Formation of ICT competence	High	1	9.1	3	27.3
	Medium	9	81.8	8	72.7
	Low	1	9.1	0	0
Use of social media to search for information about educational institutions and specialties	High	1	9.1	2	18.2
	Medium	8	72.7	9	81.8
	Low	2	18.2	0	0

context frames the evolution of career guidance. Contemporary approaches blend traditional and innovative methods, with social media offering accessibility and interactivity. Research reinforces the benefits of comprehensive guidance programmes and technology integration.

2. The methodology outlines a systematic approach to leveraging social media for effective career guidance in professional pre-higher education. Building upon the Social Career Cognitive Theory, it employs a three-tiered system of engagement, monitoring, and evaluation. Platform selection is crucial, with comparative analysis revealing LinkedIn's superior engagement and career outcomes, and Instagram's high student adoption. Continuous monitoring, evaluation, and impact assessment ensure responsiveness to student needs and adaptability to evolving career landscapes. The Performance Trends Analysis demonstrates successful implementation and coordination of the guidance strategy.
3. The experimental study aimed to confirm the effectiveness of social media-based career guidance under specific pedagogical conditions. The ascertaining stage revealed most students at the middle level across all criteria, with limited high indicators. The formative stage introduced the developed methodology, resulting in positive changes across all criteria in the experimental group, ranging from 9% to 18.2%. The study validates the effectiveness of the developed conditions, confirming the hypothesis and highlighting social media's potential for empowering students in their career development journey.

Declaration on Generative AI: During the preparation of this work, the authors used Claude 3 Opus in order to: Drafting content, Improve writing style, Abstract drafting. After using this service, the authors reviewed and edited the content as needed and takes full responsibility for the publication's content.

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Theoretical and practical aspects of using artificial intelligence technologies in the field of sound design

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Abstract

The theoretical and practical aspects of using artificial intelligence technologies in the field of sound design are considered. An analysis of modern technologies, their capabilities and limitations is conducted, the advantages and risks are examined, and the prospects for development in this field are outlined. The results of the research are aimed at increasing the understanding of the potential of AI in working with sound and determining ways to effectively implement these technologies in the creative process.

Keywords

sound design, artificial intelligence, sound creation for music, Suno AI, sound plugins, visual novels, AudioGen

1. Introduction

Modern artificial intelligence (AI) technologies are becoming an integral part of many spheres of human activity, including creative industries [1, 2]. One such area where AI demonstrates significant potential is sound design. This discipline combines art and technology to create sound compositions used in cinema, video games, advertising, music and other media. The use of AI in sound design opens up new possibilities for process automation, sound generation and interactive sound accompaniment, changing traditional approaches to working with sound.

Despite significant interest in the use of artificial intelligence in creative industries, the topic of AI application in sound design is not yet fully explored in modern scientific literature. Most studies focus on specific aspects such as sound synthesis, audio signal processing or adaptive sound systems for interactive environments. However, a holistic analysis of the theoretical foundations, practical applications, and the impact of these technologies on the industry as a whole remains fragmented.

Some works highlight the technical aspects, describing the algorithms and methods used to generate or process sound. Others focus on applied cases, such as the integration of AI in the production of music or sound effects for cinema and games. Meanwhile, a comprehensive approach that would take into account both creative and technical challenges, ethical aspects and development prospects is still lacking.

This indicates the need for deeper research that would create a general concept of using AI in sound design. This article attempts to fill this gap by analysing not only existing technologies, but also their impact on the process of sound creation, as well as outlining future prospects for this field.

2. Transformation of modern sound design

In the classical sense, sound design is the process of obtaining (generating), editing, and implementing sound elements (samples) in a multimedia composition [3]. It covers a wide range of applications,

AREdu 2024: 7th International Workshop on Augmented Reality in Education, May 14, 2024, Kryvyi Rih, Ukraine
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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

CEUR-WS.org/Vol-3918/paper350.pdf

including cinema, theatre, video games, advertising, the music industry and even architectural design of sound environments. The main principles of classical sound design include the following aspects [4]:

- **Realism and authenticity**. The main principle underlying the classical approach is the creation of realistic sounds that correspond to the visual or dramatic context.
- **Technical skill**. Sound designers rely on traditional methods of recording sound using microphones, field recorders, analogue and digital processing tools.
- **Foley art**. A special place in classical sound design is occupied by the art of creating sound effects manually, using real objects and materials to imitate various sounds. Real sounds are recorded and processed by appropriate means of artistic sound processing, such as reverberation, echo, chorus, etc., to achieve the desired result.
- **Composition and editing**. The sound designer combines sounds into a sound composition, using editing to achieve the desired rhythm, harmony and dramatic impact. That is, a synergistic combination of sound and dynamic change of images is performed.

The classical approach laid the fundamental principles of sound design, which still remain relevant. However, changes in the digital landscape pose new challenges. Classical methods of sound design have their limitations (for example, lack of adaptability, instrumental and technical limitations, time and resource costs).

The gradual development of digital technologies has also changed the principles and means of sound design. With the advent of VST (Virtual Studio Technology) and AU (Audio Units), sound designers gained access to thousands of digital instruments, simulators of analogue and digital synthesisers, classical musical instruments and effects [5, 6]. This significantly reduced equipment costs and expanded the possibilities for experimentation. The development of the gaming industry stimulated the emergence of adaptive audio systems, where sound changes depending on the player's actions or environment. Wwise (figure 1) and FMOD technologies have become the standard in the field of interactive sound design [7].

Digital sound libraries gradually began to appear – sets of pre-recorded samples that can be quickly applied to one's own projects. The use of ready-made sounds was not a new practice in itself – the 1950s-60s saw the creation of the first commercial libraries storing sounds of gunshots, natural phenomena,

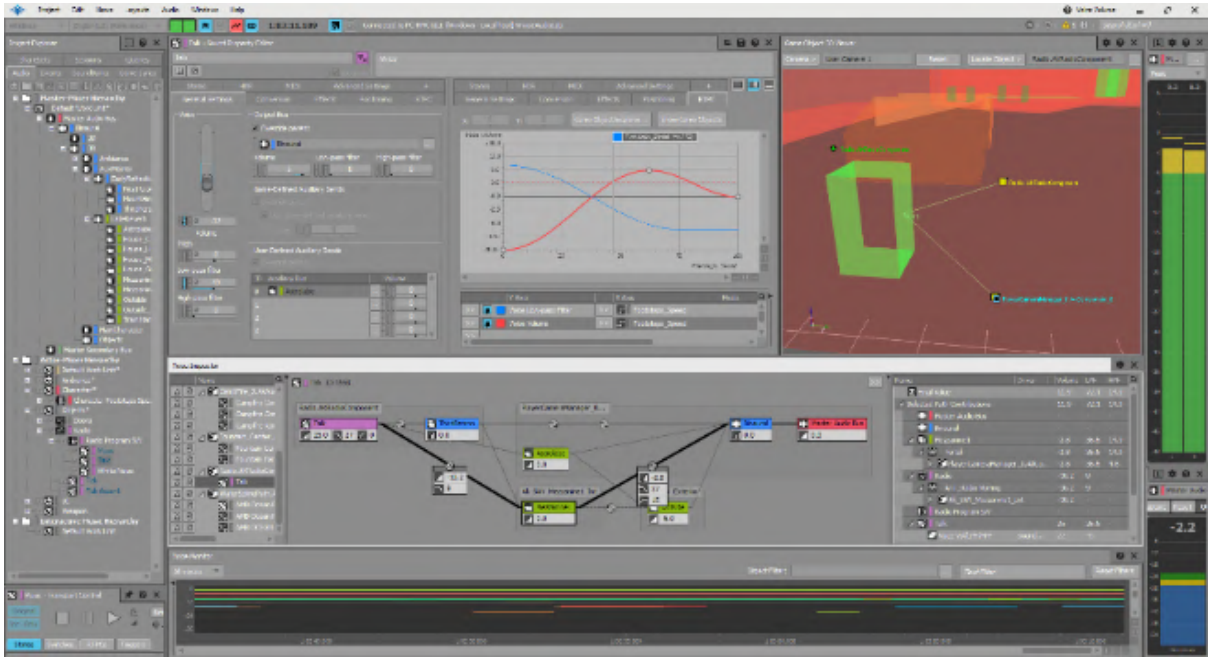


Figure 1: Wwise Software – a tool for creating sound for interactive media and video games.

transport, etc. [8]. They were recorded on analogue media (e.g. magnetic tape) and used in cinema and television.

Modern sound design has reached a level where technologies allow the creation of high-quality sound for various types of media – from cinema and video games to advertising and virtual reality. Audio processing tools have become more powerful, and access to large sound libraries, virtual instruments and modern technical means for recording and processing sound have greatly simplified the process of creating sound content. But the demand for constant improvement remains unchanged. That is why the question arises: how to adapt and use the possibilities of artificial intelligence, which continues to develop comprehensively, in the sound design industry. And how expedient is such use?

3. Artificial intelligence in sound design: main directions

The use of artificial intelligence for sound generation has become one of the most promising areas in the field of sound design. At a basic level, this process is based on the ability of algorithms to learn from large volumes of audio data, analyse them and create new sound textures that can be used in music, cinema, video games and virtual reality [9].

In the early stages of development, artificial intelligence algorithms worked primarily with existing sounds. They could restore audio, remove noise or imitate the sound character of specific instruments. However, with the development of machine learning [10] and neural networks [11], AI has become capable of creating completely new soundscapes that did not exist before. For example, generative adversarial networks (GANs) allow systems to synthesise sounds that have a natural timbre, and recurrent neural networks (RNNs) learn to predict the next sound segments, creating a continuous audio stream.

One of the most striking examples of AI applications is the creation of sounds for music. Algorithms analyse thousands of music tracks, extracting patterns and harmonies, and then generate melodies or rhythms. Programs like AIVA (Artificial Intelligence Virtual Artist) are capable of creating entire compositions in various genres, providing composers with a foundation for further work [12]. In the field of electronic music, AI is often used to create unique samples or synthetic textures that can be integrated into compositions.

At the beginning of 2024, the Suno AI network gained a high level of popularity [13]. Suno AI is an innovative platform that uses artificial intelligence to generate music based on text prompts. The user enters a description of the desired song, specifying the style, genre or theme, and the system creates a corresponding composition. This process takes about two minutes, after which the user receives two versions of the track: one with vocals, the other instrumental.

Suno AI technology is based on artificial intelligence models such as Bark and Chirp, which are capable of generating not only instrumental music but also adding vocal parts to songs. The algorithm analyses the entered text, determines its rhythmic and semantic features, and then synthesises a melody and harmony that match the given description. The vocals are synthesised taking into account the rhythm and intonation of the text, giving the song a natural sound.

The system uses an approach similar to large language models, such as ChatGPT [14]: it splits the text into individual segments (tokens), studies millions of usage variants, styles and structures, and then reconstructs them on request. However, creating audio, especially music, is a more complex task, as it requires taking into account many parameters such as melody, harmony, rhythm and timbre.

Of course, the tracks generated by both Suno AI and other platforms and models have noticeable subjective flaws, which most often manifest themselves in distortions in vocal parts, sharp changes in volume or banal misunderstanding or neglect of prompts. Artificial intelligence can work much more accurately with small sounds. Classic elements of sound design are various sound transitions, for example, a gradually increasing sound (rise), a sound of impact (hit), a sound of cutting air (whoosh), etc.

Artificial intelligence is able to generate and process such short sound effects with high accuracy due to its ability to analyse thousands of samples and extract key sound characteristics. These effects have a

clear structure and predictable dynamics, making them ideal material for algorithm work. AI models can create variations of hits, rises or noises based on text descriptions or user settings, providing precise adjustment of the duration, frequency spectrum and amplitude of each sound.

In addition, thanks to machine learning technologies, artificial intelligence can automatically select sounds for different scenes, creating smooth transitions and adapting them to the visual content. For example, AI can generate a whoosh sound of varying intensity depending on the speed of an object in the frame or synchronise impact effects with moments of climax.

There are already services that provide the ability to create cinematic sounds with a text prompt. But such sounds are only a small part of sound design. For us, sound design is primarily a complex sound landscape, an immersive global environment. Is artificial intelligence capable of forming something like this?

Immersive environment sound design requires not only layering sounds on top of each other, but also fine-tuning spatial acoustics, dynamics and the emotional content of each layer. In the real world, sounds interact with each other in unpredictable ways – echoes in space, gradual fading or swelling, the influence of textures of materials and objects that create or reflect sound. It is difficult for algorithms to reproduce this chaos and versatility of the sound environment in the same way as human hearing and perception.

Currently, artificial intelligence does an excellent job of reconstructing real environments through recordings and spatial analysis, but creating completely fictional sound landscapes that have no analogues in reality requires creative intuition. A human sound designer works not only with sounds as such, but with a concept – they create a story through sound, using audio as a tool to evoke emotions and build atmosphere.

However, there are also positive aspects. Artificial intelligence algorithms are becoming increasingly effective in creating procedural sound landscapes. They are able to analyse visual sequences or text descriptions and generate corresponding sound environments, automatically adding necessary elements: the sound of wind, raindrops, city bustle or any other simple ambient.

Artificial intelligence cannot fully construct a multi-layered sound environment. But it can be used as a tool that provides a certain foundation to work with. For example, it is possible to create simple patterns of classical instruments in a given key and rhythm, perform their gradual processing using classical means in any sound editing environment, mix the tracks, supplement them with various generated sounds, and further integrate the created composition into complex multimedia environments.

Another equally important aspect is the integration of artificial intelligence technologies into various plugins for working with sound. Often these are a wide variety of tools for different tasks, which have appeared quite a lot recently. AI assistants are used to perform general mastering (such as the built-in assistant in Izotope Ozone 10/11), for individual tasks such as compression, limiting, saturation, equalisation, etc. AI plugins are trained on large volumes of audio data. Developers train the neural network based on various recordings manually processed by professional sound engineers. The model analyses how classical tools for saturation, compression or limiting work, and learns patterns of effect application depending on the type of sound, genre or processing style.

When the user loads the plugin, the algorithm performs a multivariate analysis of the audio signal – analyses the frequency spectrum, dynamics, harmonics and noise level. AI models are able to detect problem areas or potentially weak zones and suggest processing parameters. Practical experience shows that these parameters are often not optimal, but can be used as a basis for further work with sound.

Much more interesting from the point of view of sound design are plugins such as Synplant 2. The Genopatch technology (figure 2) built into the plugin allows generating a variety of new sounds based on a single loaded sample [15]. The unique capabilities and interface of Synplant 2 promote experiments in the field of intuitive sound design, allowing to explore how non-standard methods of interaction with technology can influence the creative process.

Considering all of the above, we can note that artificial intelligence is already transforming the field of sound design today, opening up new possibilities for creativity and automation. Despite significant achievements, AI technologies in sound design face certain significant challenges: limited emotional depth of generated sounds, complexity of creating complex immersive environments, and various

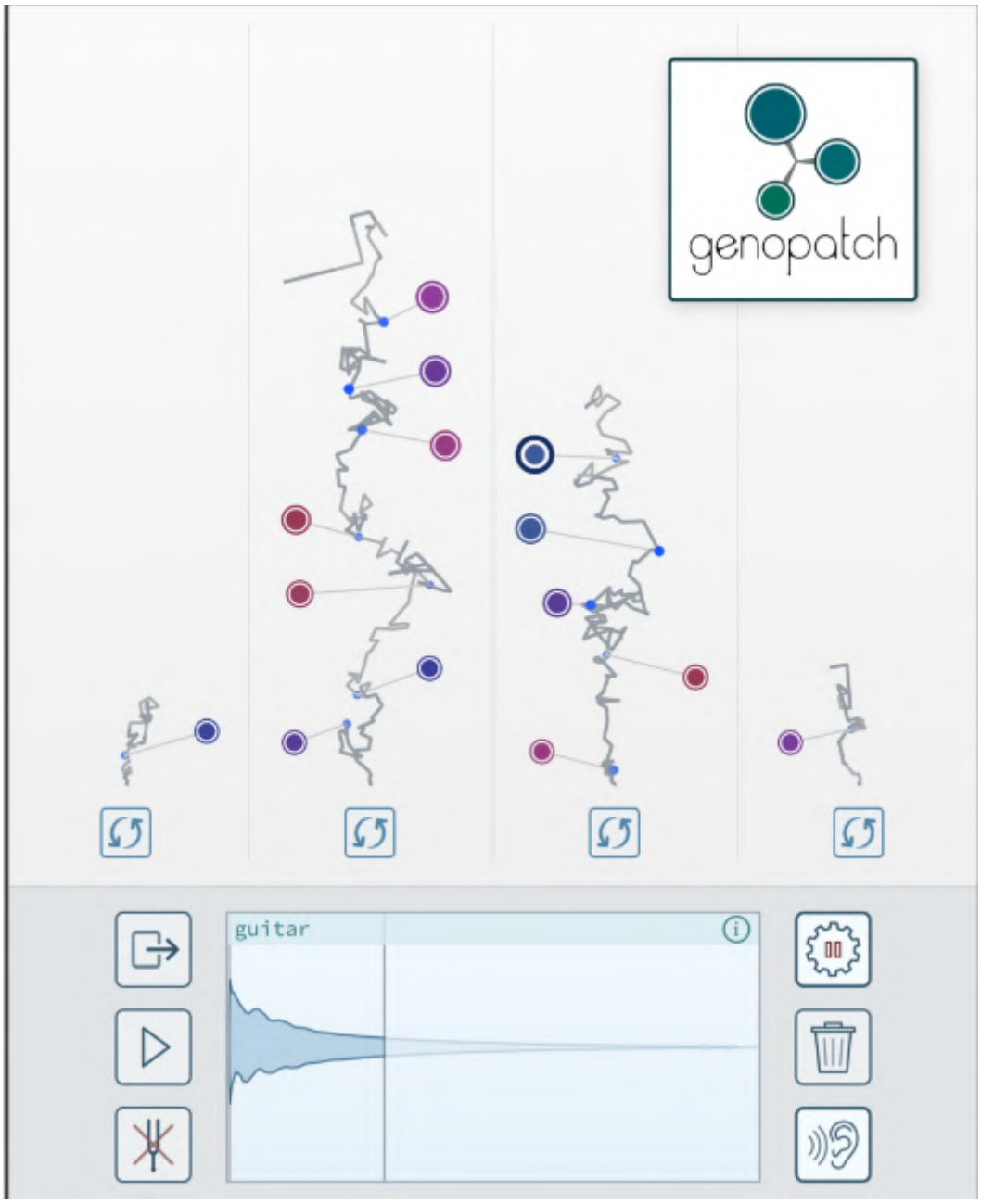


Figure 2: Working in the Genopatch editor.

technical defects that can distort the perception of the overall picture. However, these limitations stimulate the development of the industry and create space for improving algorithms, integrating new approaches and synergy with human creative ideas. AI does not replace sound engineers, but becomes a powerful tool that helps accelerate the workflow and expand creative horizons.

Now, let's demonstrate the possibilities and ways of applying artificial intelligence technologies in sound design through practical experience.

4. Practical aspects of using artificial intelligence technologies in sound design

In this part, as an example of the possibilities of using AI in sound design, we will form a simple sound design for several scenes that are planned to be used in a visual novel. Visual novels (VN) are a genre of

interactive games where the main emphasis is on the plot and characters, and sound plays an important role in creating an emotional response. The scenes themselves were created using Dalle-E 3 and refined in Adobe Photoshop (figure 3).



Figure 3: Prepared scenes.

To begin with, we break down the scenes into components and determine the overall mood and which sounds we need (figure 4).

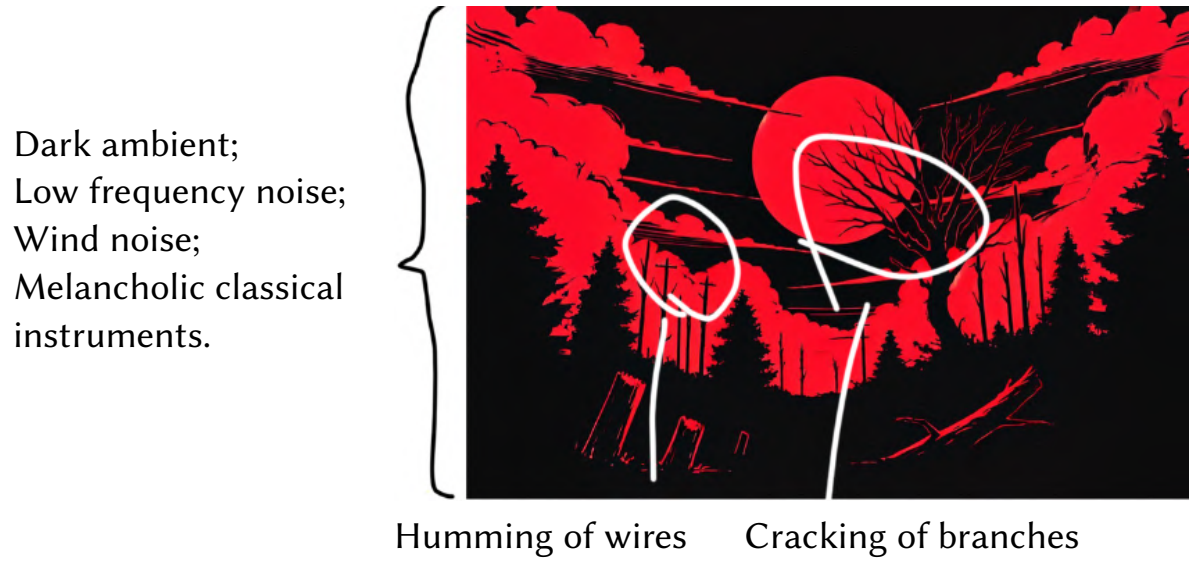


Figure 4: Determining sounds for the scene.

Now let's determine the necessary artificial intelligence tools. For forming the general landscape, the aforementioned Suno AI from the previous section will work. Using the following prompt, we generate two compositions for download: Violin and piano, melancholic style, slow tempo, dark ambient. We transfer the downloaded result to the FL Studio environment and perform the following sequential processing: slowing down, equalisation, adding reverb and echo effects using the Crystalize granular generator from the developer SoundToys (figure 5).

It is worth noting that the recording generated in Suno AI without further processing would not fully correspond to the general concept of sound design for this project. As already mentioned above, Suno AI often does not interpret prompts very accurately, which leads to problems with generating music in less well-known genres. However, artistic processing tools allow to significantly change and improve the nature of the input sound and adapt it to the needs of the project.

Unlike Suno AI, the AudioGen AI instrument handled the prompt more accurately, generating distant humming of electric wires and cracking of branches with a rather short request (figure 6).

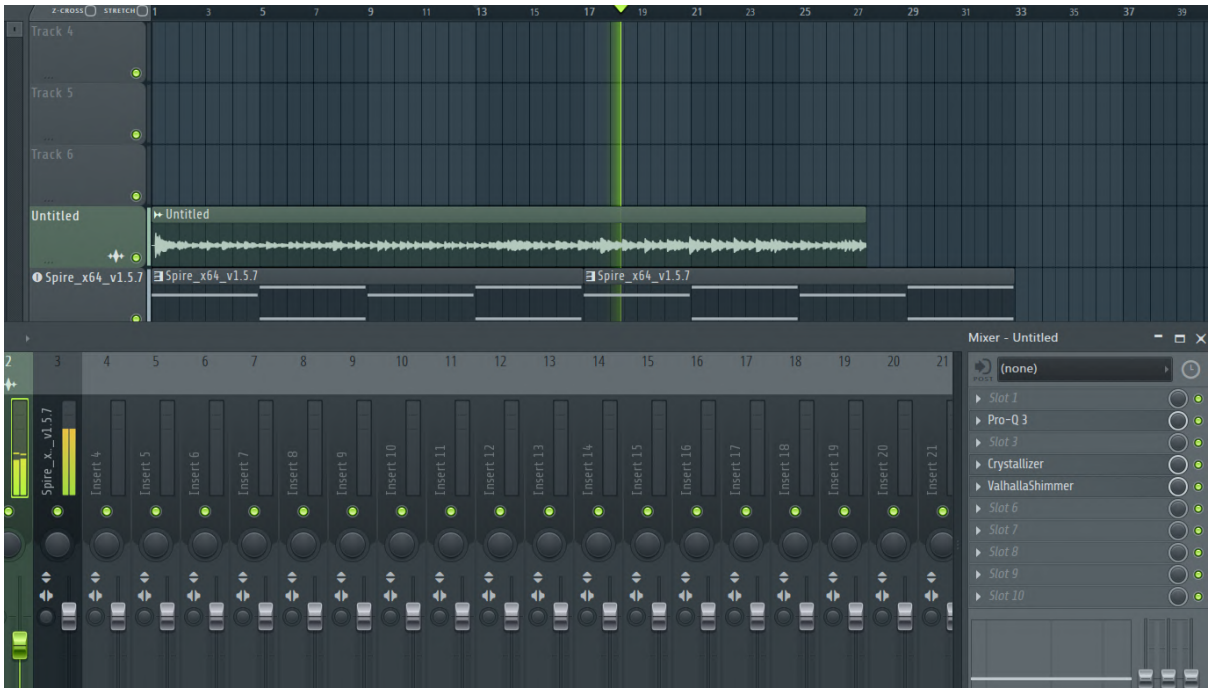


Figure 5: Work in the FL Studio environment.

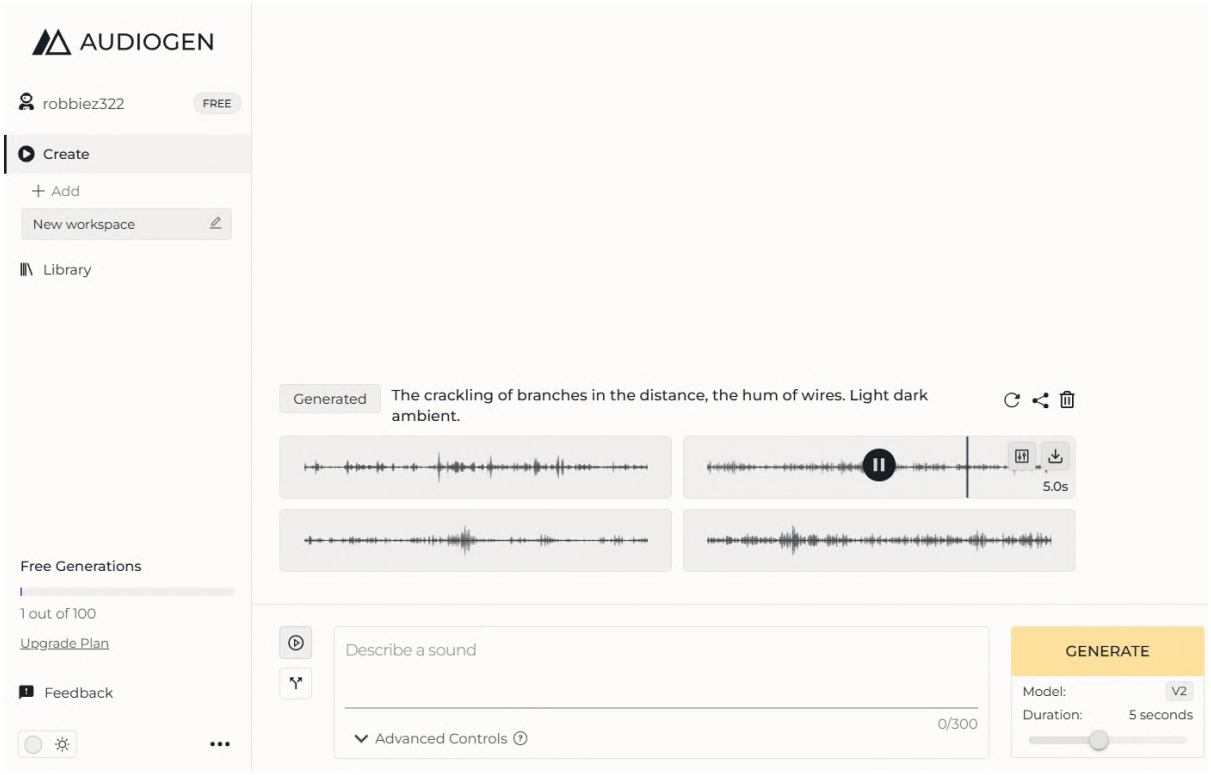


Figure 6: Work with the AudioGen tool.

To create various variations of the sample generated using AudioGen, we will use Synplant2 and its Genopatch technology. We load the sample into the plugin environment, after which Synplant2 automatically generates new sound samples based on the provided one (figure 7).

After combining all the generated sounds, we have as a result a simple but subjectively quite high-quality sample of sound design for scenes from a visual novel. Thus, based on practical experience,



Figure 7: Generation of new sounds using Synplant2.

the feasibility of using artificial intelligence technologies as a tool for quickly obtaining the necessary sound samples for their further processing and combining into a coherent composition was confirmed.

5. Conclusions

The article provides a thorough analysis of the theoretical and practical aspects of using artificial intelligence technologies in the field of sound design. The current state of the industry is highlighted, considering its technical capabilities and creative challenges. A study of classical and modern tools for forming sound environments is conducted.

It has been proven that artificial intelligence significantly changes the traditional approach to sound creation, providing process automation, time savings, and expanded possibilities for experimentation. For the first time, a detailed analysis of the main trends and directions of the impact of artificial intelligence on sound design is presented. Special attention is paid to tools such as Suno AI, AudioGen, Synplant2, which demonstrate significant potential for generating sound textures and integration into creative projects.

The practical aspect of the research is based on the example of creating a sound accompaniment for visual novels, where artificial intelligence was used to generate musical compositions and sound effects. These materials, after further processing, can become the basis for high-quality full-fledged sound design. It is important to emphasise that although AI tools provide speed and adaptability in

working with sound, their results often require refinement to match creative ideas.

In this article, for the first time, an integrated approach to the use of various artificial intelligence tools for creating sound design is proposed. This approach takes into account both technical capabilities and creative needs. The study outlines the advantages of modern AI algorithms, such as efficiency in creating short sound effects, as well as their limitations, including difficulties in forming complex immersive sound landscapes.

Also, for the first time, the article presents a methodology for selecting artificial intelligence tools for specific tasks in the context of sound design for multimedia projects. For example, it is determined that tools such as Suno AI are appropriate for creating music and musical effects, AudioGen for generating sounds of certain environments, and Synplant2 for editing sounds. This methodology is formed on the basis of practical work with these tools and subjective evaluation of the generation results.

The overall results and prospects for further development of this problem can be defined as follows:

- A study of the main directions of using artificial intelligence in sound creation has been conducted, including the generation of musical compositions, short sound effects, and procedural sound landscapes. It is shown that tools like Suno AI, AudioGen, and Synplant2 are able to effectively perform sound generation and processing tasks, which greatly simplifies the complex process of creating sound design;
- The article presents an example of creating sound design for visual novels, which illustrates the capabilities of AI for quickly obtaining basic sound textures. It is shown that artificial intelligence can be used to automate sound creation with further processing and refinement, which allows achieving high-quality final results;
- An integration approach is proposed, which consists in using various artificial intelligence tools for different tasks that may include short musical compositions, simple sound landscapes, and short sounds. Subjective evaluation of the quality of the created samples shows that they are quite suitable for use in various multimedia projects.

The practical significance of the obtained results lies in increasing the efficiency of sound design creation processes through the integration of artificial intelligence technologies. In particular, the proposed methods allow automating routine tasks, such as generating basic sound textures and creating simple sound or musical effects. This reduces the time and resources required for work and allows designers to focus on the creative aspects of projects.

Prospects for further research are primarily related to improving algorithms for creating immersive sound environments, deepening the synergy of AI and human creativity, and more active integration of generated sounds into multimedia projects. These prospects demonstrate the potential for further transformation of the sound design industry, expanding the capabilities of creative professionals and stimulating the development of innovations in the use of artificial intelligence.

The study confirmed the practical value of artificial intelligence in transforming sound design, expanding the toolkit for creating sound compositions and opening up new horizons in creative industries.

Declaration on Generative AI: The authors have not employed any Generative AI tools.

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Experience in developing and implementing virtual tours using 360° video technology in the educational environment

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Abstract

The article examines the specifics of such a modern immersive technology as 360° video. Its characteristics, varieties, and possibilities of application in the educational process are considered, including the peculiarities of training specialists in the publishing and printing industry, which requires a combination of theoretical knowledge and practical skills. 360° video technology allows creating interactive and immersive content that provides an immersive effect, demonstration of real production processes, modelling of complex situations and learning technologies. The potential of 360° video technology to increase the efficiency of learning through visualisation of material, interactivity and active interaction of students with content is determined. The experience of developing and implementing 360° video technology in the educational environment within the framework of an educational project on the development of a virtual tour is described. The article presents the methodology for implementing an educational project to create 360° video, which includes theoretical training, mastering software and hardware, and practical work on creating and processing video content. The practical result of the study is the creation of a virtual university tour, demonstrating the application of innovative solutions in the professional training of students.

Keywords

sound design, artificial intelligence, sound creation for music, Suno AI, sound plugins, visual novels, AudioGen

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1. Introduction

Changes in society, technologies and the labour market require constant modernisation of educational programmes and teaching methods. Higher education should prepare specialists capable of flexibly adapting to new challenges. The use of modern technologies, which are becoming an integral part of any field of activity, is a key aspect of such training. Among the latest technologies, immersive technologies, which are gaining increasing popularity and widespread use, are of particular interest.

Today, augmented reality technologies are characterised by active implementation in world educational practice [1], bringing education to a significantly new level. They form new approaches to teaching and learning educational material and a new education system in general, acting as one of the indicators of educational innovation [2, 3].

As noted by scientists, immersive technologies are used as a collective nomination for human interaction with space, information, content on the verge between the real and the unreal product of virtual, augmented or mixed realities [4, 5]. That is, immersive technologies are a general name for technologies that provide an experience of full or partial immersion in an alternative space or a combination of it with the real world [6, 7]. Immersive technologies include:

- virtual reality (VR),

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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

- augmented reality (AR),
- mixed reality (MR),
- extended reality (XR), which combines AR and VR technologies,
- 360° photos and videos.

All these types of immersive technologies provide new approaches to the implementation of educational activities beyond the previous limitations of human perception. They represent innovative methods of creating, demonstrating and human interaction with content. The essence of these technologies is to combine the real world with the virtual one. By expanding human experience and going beyond spatial limitations, they immerse the user in the virtual world and provide an opportunity to perceive immersive content differently: not only to see and hear, but also to touch or connect other sensory sensations, or even to "be" a part of it. Scientists agree that the use of immersive technologies in educational practice has many advantages [8, 9, 10], in particular, interest, increased motivation to learn, visualisation of educational content, personalisation of learning, providing feedback, real experience and communication, development of critical thinking.

Among the immersive technologies used in education, AR and VR technologies are most often mentioned. Their potential for creating engaging and effective learning environments is truly undeniable [11]. However, no less interesting and relevant is the 360° technology (panorama and video), which offers a more accessible and simpler way to immerse users in different contexts.

The directions of application of immersive technologies in higher education are also very wide. In the domestic educational space, there is experience of their use in the training of future specialists in the field of linguistics [12], mechanical engineers [13], teachers [14], etc. However, the possibilities of their application in the training of publishing and printing specialists remain insufficiently studied, which opens new prospects for research.

The aim of the study is to reveal the specifics of 360° video technology, determine its didactic potential and possibilities of application in the professional training of future specialists in publishing and printing in the context of the implementation of educational projects (using the practical experience of creating virtual video tours as an example).

2. Results

The modern educational process, which in today's conditions is forced to move into the digital space, requires a review of approaches to the organisation of the information and educational environment and the formation of educational content. Under such conditions, the use of immersive technologies is not just a tribute to a popular educational trend, but an urgent necessity to involve students in learning and make their activities informative, exciting and effective.

This is especially important in the training of specialists in the publishing and printing industry, which combines technical, production and creative aspects. The training of specialists in this field requires extensive use of visual materials, such as samples of printed products, demonstrations of production processes and equipment. The use of immersive technologies will allow students not only to theoretically master the material, but also to gain practical experience, will provide an opportunity not just to passively observe, but to actively interact with the educational content. This allows for a deeper immersion in the material, consolidation of knowledge and makes the learning process more interesting and effective [15].

However, despite the fact that scientists and educators make significant efforts to implement immersive technologies in educational practice, their widespread use is complicated by a number of factors. In particular, technological, organisational and financial challenges hinder the large-scale virtualisation of learning [16]. In view of this, 360° video technology is a more convenient, realistic and accessible version of VR [17].

360° technology is one of the most recognisable forms of immersion technology that creates a virtual reality experience by which users can immerse themselves in a 360° digital environment. 360° technology

comes in two types: 360° panorama and 360° video. 360° panoramas or videos are visual constructs in which images or videos in all directions are captured and presented simultaneously [18].

Within the framework of this study, the technology of 360° video is of particular interest. It is a specific video format that has the characteristics of virtual reality, but at the same time differs from it in the necessary real recording situation without programmed virtual environments [19]. Unlike traditional flat 2D video clips, 360° video is recorded simultaneously in all possible directions with a viewing angle of 360° horizontally and 180° vertically, giving the viewer expanded access to the video object. In addition, due to its specifics, this technology, when viewing, really gives the impression of being present in the scenes, provides opportunities for the viewer to change the viewing parameters in several viewing angles and from any perspective and interact with the elements of the scene.

That is why 360° video is often called spherical or immersive video. In turn, 360° video can be of several types [18, 20]. Figure 1 shows its varieties, depending on the type of image used, the method of creation and the interactive capabilities that the user receives to interact with the content during viewing.

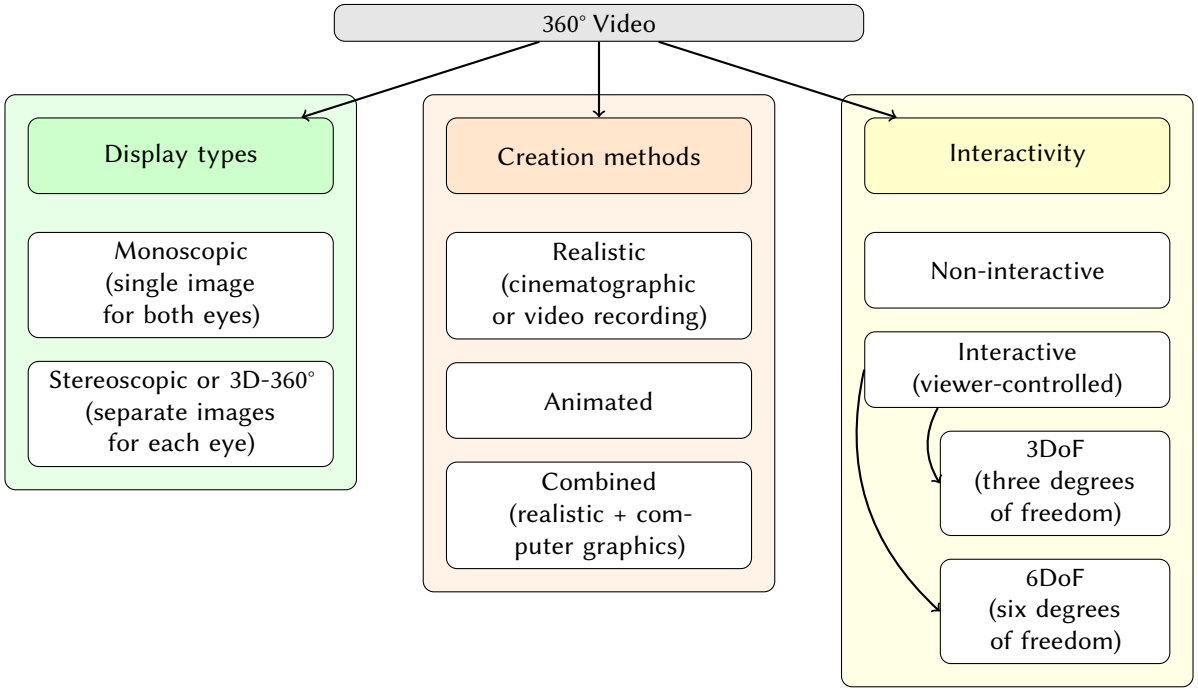


Figure 1: Types of 360° video (based on [18, 20]).

On the one hand, 360° technology is a kind of video, but it differs significantly from the usual video materials, because it provides a feeling of immersion in the broadcast environment, which brings it closer to augmented and virtual reality, because like AR/VR, it conveys a sense of presence and allows interaction with the virtual environment. However, unlike AR/VR, 360° video only creates the effect of presence, allowing the user to freely rotate and view the image from any angle, as if they were directly at the filming location, but does not provide such powerful sensory sensations of full presence.

For example, 360° video that supports 3DoF (three degrees of freedom) gives the user the following capabilities: look forward and backward, side to side, and shoulder to shoulder, that is, in any direction in which the head can rotate. You can also use hand controllers to manipulate some objects or perform certain actions, but 3DoF limits you to being tied to one place, so it is often called fixed virtual reality. 6DoF means six degrees of freedom: the ability to change the position of the head and body while viewing content [18].

For example, VR uses the power of computer technology to create a simulated environment that can be explored and interacted with fully immersed and replaces the “real” world with an alternative one, while AR overlays computer-generated images on an existing space in the real world, complementing

and expanding it and thus providing an exciting learning experience [21, 22]. And although interaction with the created 360° environment is quite limited compared to AR/VR, a great advantage of this technology is its greater simplicity and accessibility in creation and use.

Table 1 shows a comparison of the features of the three immersive technologies in terms of such important characteristics as the properties of the projected environment, the level of immersion and the type of interaction in the immersive environment, the equipment for its use, the design approach and possible directions of application in the educational process.

Table 1
Comparison of AR, VR and 360° video (based on [21, 22]).

Characteristic	**VR**	**AR**	**360° video**
Environment	Completely artificial	Overlaying artificial elements on the real physical world	Real, but with panoramic view
Level of immersion	Maximum	Medium	Medium
Type of interaction	Active, with objects	Active, with objects and the real world	Passive, content viewing, viewing control
Equipment for use	VR headset, controllers	Smartphone, tablet, special glasses	Smartphone, PC, VR headset
Content creation	Complex, requires full computer modelling of an artificial world	Relatively simpler, overlaying computer-generated images on the real world through special devices	Simpler, does not require computer modelling, shooting with a 360-degree camera
Application in education	Simulations, virtual laboratories	Interactive textbooks, virtual excursions	Virtual excursions, tours, process demonstrations, etc.

Given its features, 360° video is gaining popularity in the field of education. Scientists determine the powerful didactic potential of this technology [19, 23, 24]. 360° videos allow students to observe a scene in any direction, giving them the opportunity to virtually explore an imaginary world or view a real recording of the real world. On smartphones, when they move and rotate their devices left and right or up and down, the images they see move in perfect synchronisation; on laptops and desktops, they can easily navigate spherical 360-degree videos by clicking and dragging navigation buttons, or using a mouse or touch screen [23]. Thus, 360° technology allows creating interactive and immersive learning environments that help gain new knowledge and skills in an engaging and effective way.

With the help of this technology, compared to traditional learning, it is possible to create a learning experience that would be impossible or extremely difficult in dangerous or hard-to-reach conditions [25]. Thanks to it, students can visit remote or restricted places, such as historical and cultural monuments, museums, laboratories, industries and distant countries; study complex concepts in a more accessible and interesting way; conduct virtual tours, as if being among the exhibits and explore objects from all sides. In each of these cases, learners act as active participants in the learning process, not passive consumers of information.

Regarding the peculiarities of training future specialists in the publishing and printing field, 360° technology can become a powerful and accessible tool for creating immersive educational materials and building an educational environment. Considering the specifics of the industry, 360° materials can be used to provide the following educational goals:

- demonstration of production processes and functioning of printing equipment (360° video allows to clearly show all stages of production and creates the effect of full immersion in the professional environment);

- modelling of complex, risky production situations, minimising the risks of errors, which is critically important in real production;
- research of printing technologies and comparison of different technical solutions;
- familiarisation with printing materials, demonstration of their properties and peculiarities of use;
- demonstration of interaction of specialists in production, which helps to better understand the coordination of work in the printing shop;
- practical study and analysis of the principles of composition construction, selection of fonts, textures and colour schemes in real projects, carrying out a detailed study of samples of publication design in an extended space;
- study of the history of the industry and its current state;
- development of "visual perception" and formation of creative skills;
- creation of presentations and development of communication skills (360° video is an innovative tool that students can use to create special and visual presentations of their work and research).

In form, such 360° educational materials can be very diverse: virtual excursions and tours to real enterprises / exhibitions / galleries / museums, virtual demonstrations, virtual production quest rooms, simulators, seminars, educational videos. In addition, 360° video can be combined with other technologies (for example, adding AR markers or 3D models). A set of materials on one topic can be structured in the form of an immersive educational module, as a separate completed block of learning, and become an important component of an interactive educational environment.

However, 360° video can be not only an educational technology that helps in the study of certain academic disciplines, but also an object of study and a learning tool. Thus, at the Department of Computer Multimedia Technologies of the State University 'Kyiv Aviation Institute" there are a number of educational disciplines, the purpose of which is to study various interactive and immersive technologies, including 360° video technology. And one of the best ways to master them is not just a theoretical acquaintance with the specifics and features of the technology, but the implementation in practice of a real project using it. In this way, students gain real practical experience working with modern technologies, taking on the functions of creative content developers.

Based on this, at the Department of Computer Multimedia Technologies, together with students, an educational project was implemented and a 360° video tour of the university territory was created. The experience of implementing an educational project showed that it is most appropriate to organise it in several consecutive stages (figure 2).

Before starting to create a real 360° video, it is necessary for students to already have a sufficient set of practical skills in working with a set of tools. They master various programs and equipment necessary for work: they acquire practical skills in the use of hardware (photo and video cameras, PCs, other devices) and software (video and audio editors, editing programs, etc.). In addition, they already have knowledge of composition construction and optimisation of visual content (colour adjustment, light, aesthetics of the frame).

The second stage is theoretical preparation. Students need to be introduced to the specifics of the new technology. This stage involves assimilation of the essence of 360° technology, its capabilities and scope, basic concepts and terminology related to 360° and theoretical aspects of the application of this technology in real projects. It is also important to acquire initial knowledge about the principles of operation of 360° cameras, features of shooting and processing of this type of content.

Having theoretical knowledge and basic skills, the next step for students is to move on to the practical stage: the implementation of a real 360° project. They were given a specific task, which was to create a 360° video tour of the university territory. The project itself was implemented in two major stages. The first was to create video materials, and the second was to process them and compile them into a single material with subsequent publication on the Internet for further viewing.

At the first stage, an analytical review of existing similar materials was carried out, the concept and script of the video were developed, equipment and software were selected, and video shooting and synchronous recording of the sound accompaniment were conducted. The type of video tour

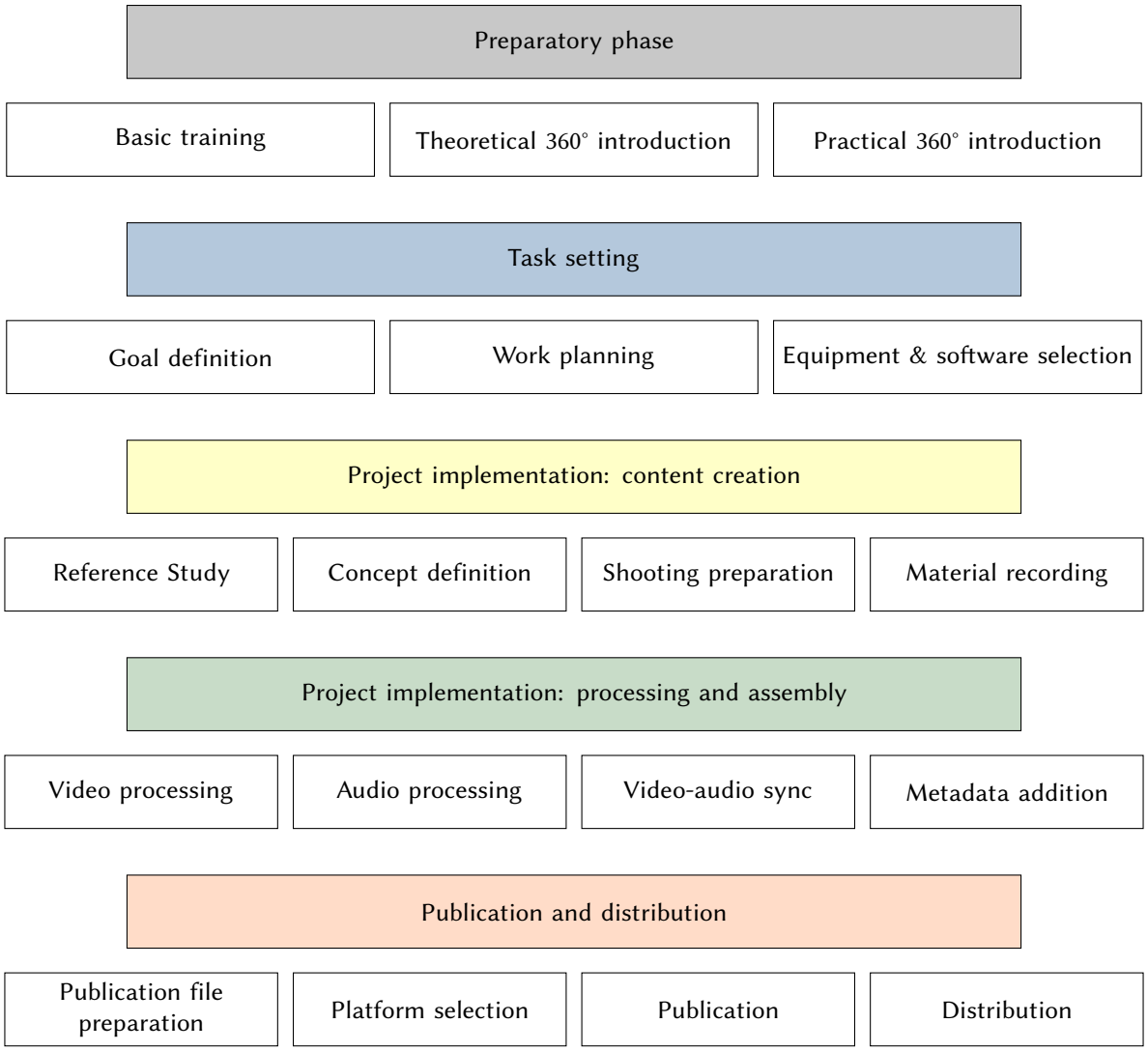


Figure 2: Stages of implementation of an educational project to create a 360° video.

that was created is a review of notable places with a presenter. This format is characterised by high informativeness, is emotional and provides visual contact with the audience.

Technically, the 360° video was created by simultaneously shooting two 180° frames together. That is, two 180° shots make up one 360° frame. To do this, you need to use special 360° cameras that have special characteristics that distinguish them from ordinary video cameras. The main difference is that the 360° camera immediately takes a panoramic image, covering the entire space around without the need to use multiple cameras or take separate frames. This makes the shooting process simpler and more accessible for new users. The user can also easily select the desired parameters for shooting, and the captured material is ready immediately for processing, and the video processing process itself takes less time.

The Samsung Gear 360 camera was used for shooting due to its advantages such as affordability, wide setting options during shooting, compatibility with processing programs, and large memory capacity. A tripod and a smartphone with a downloaded application were also used, where the necessary camera settings were set.

An important task at this stage was the preliminary sketching of frames, which included detailed planning of their compositional construction. Special attention was paid to determining the line of symmetry and the horizon line, which play a key role in creating a balanced and harmonious image. The distance from the camera to the presenter and key shooting elements was also calculated, which allows

the objects to be correctly positioned in the frame, ensuring their optimal visibility and interaction in space. Such careful planning of the compositional construction helps to avoid technical errors during 360° video shooting and ensures a high-quality final result, both in terms of technical implementation (focusing, object placement) and aesthetic perception of the frame. Figure 3 shows the sketching of the frame and the captured 360° frame.

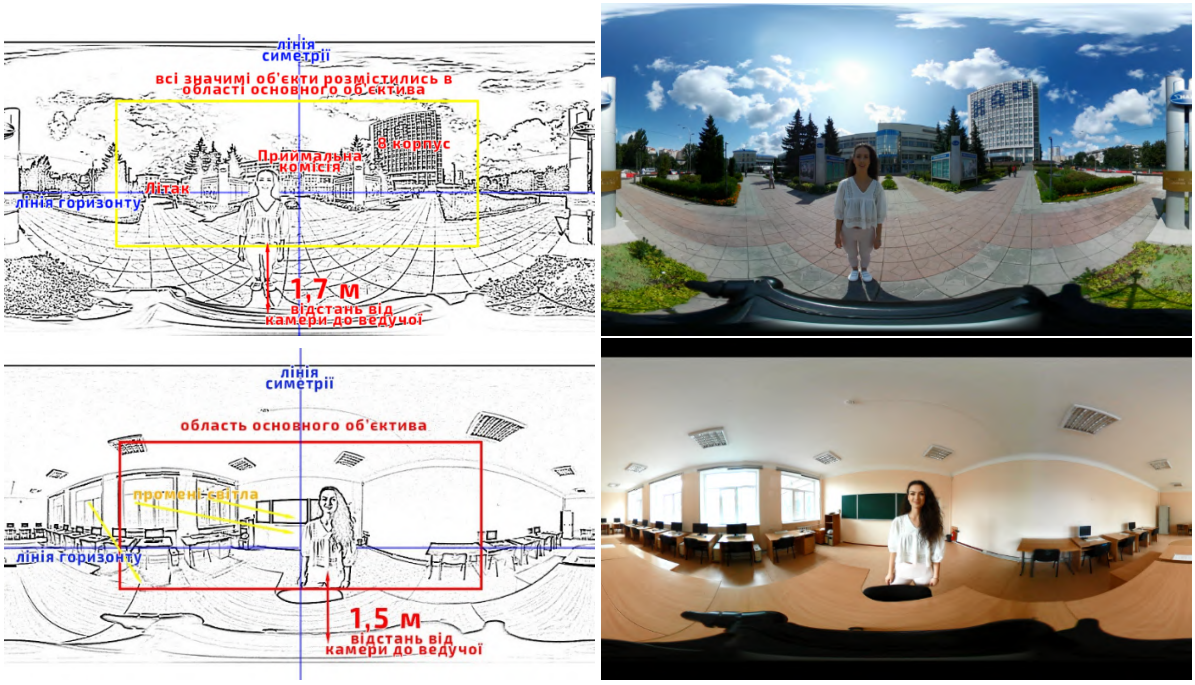


Figure 3: Sketch and captured frame.

At the second stage, all the captured materials were processed (video stitching, frame cropping, colour correction, sound processing, video clip editing) and exported in 360° video format. A set of software was used to process the materials. In Gear 360 ActionDirector, the videos obtained from the two lenses were stitched together into one video sequence, the best frames were selected and the entire video material was trimmed, and colour correction was performed. This program was chosen because it comes with the camera and does not require additional costs for purchase, and it has many additional technical possibilities for post-processing the captured video (setting transitions, overlaying titles, optimisation, etc.) like other well-known powerful applications. Figure 4 shows the video stitching process.



Figure 4: Video stitching.

In Adobe Audition CC, the audio accompaniment was processed, audio tracks were cleaned of noise to improve the sound. In Adobe Premiere Pro, video and audio tracks were synchronised and background music was added.

In order to distribute the created 360° video, the participants of the educational project finalised the metadata of the file so that it would be recognised by video hosting services. For this purpose, Spatial Media Metadata Injector was used. Figure 5 shows the final material of the 360° video tour placed on the website of the Faculty of International Relations.

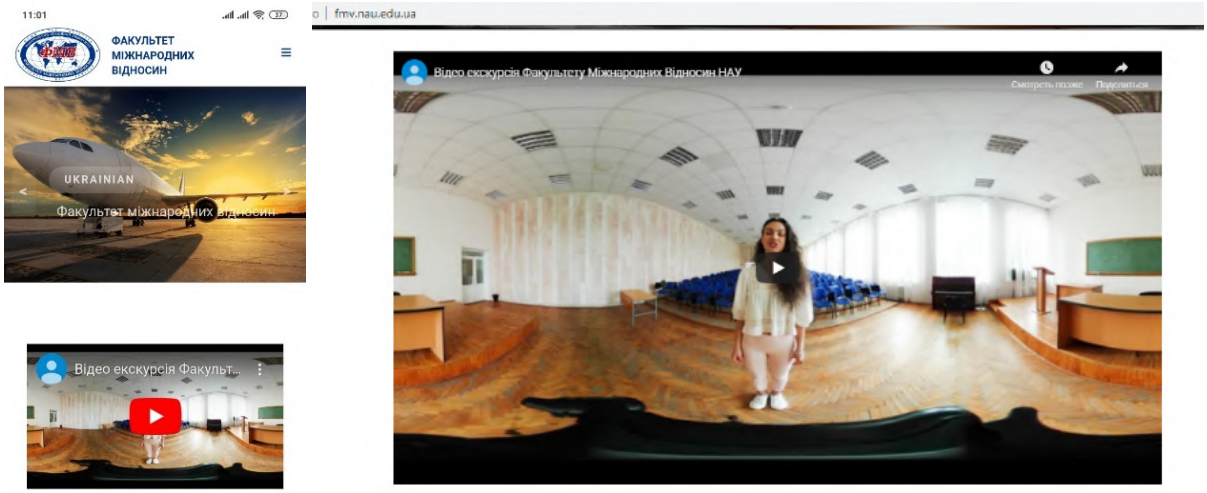


Figure 5: 360° video tour.

As you can see, although 360° video technology is simpler than full-fledged VR, it requires the use of certain hardware and software components and the availability of special knowledge and skills. When it comes to software solutions, special programs and applications are necessary, with the help of which you can create, edit and play engaging content. Appropriate hardware is also necessary, which is used both at the stage of creating and processing materials, and is necessary for viewing immersive content. With their use, you can implement projects that are extraordinary in appearance.

The Department of Multimedia Systems and Technologies of the Simon Kuznets Kharkiv National University of Economics, in cooperation with the Department of Computer Multimedia Technologies of the State University "Kyiv Aviation Institute", is developing another direction of using various interactive and immersive technologies in the educational process. Thus, when creating the content of multimedia didactic complexes for the digital educational space of the educational-professional program 'Technologies of Electronic Multimedia Publications", 360° video technologies are used. This project involves structuring knowledge based on the approach of Nonaka and Takeuchi [26], taking into account the peculiarities of the educational process in pedagogical design.

Of the four types of knowledge (unformalized, weakly formalised, conceptual, systemic scientific-theoretical knowledge), the project selects the first two types of knowledge for a given topic, which provide answers through visual and verbal tools to the questions: "how is it done", "how is it used and why"; "how is it designed and manufactured". The use of 360° video technology allows solving a wide range of didactic tasks: ensuring the perception, memorisation of knowledge, ways of action (including at the level of application in a changed situation), connections and relations in the object of study; establishing the correctness of the assimilation of educational material; ensuring the assimilation of knowledge and methods of action [27]. This approach is advisable to use to create visual content for such disciplines as "Packaging Design", "Illustration", "Computer Animation and Virtual Reality", "3D Modeling".

As part of the international project "Methods of Distributed Development of Computer Games", students of EPP "Technologies of Electronic Multimedia Publications", who are engaged in the scientific circle "Augmented Reality and Computer Games: Methods of Content Development and Animation", took part in the Online Pitching Event at the University of Bayreuth (Germany). The results of such testing showed the feasibility of continuing research and development of immersive technologies in this direction.

3. Conclusions

360° video technology, which is based on the creation of panoramic content, provides the effect of presence and immersion. Its difference from AR/VR is greater accessibility due to lower hardware requirements and a simpler creation process. And although the level of interactivity in 360° video is limited compared to AR/VR, where the user has the opportunity to actively interact with the virtual environment, this technology has significant didactic capabilities, in particular, in the training of publishing and printing specialists. Due to the possibility of visually rich immersion, this technology allows students not only to effectively master educational material, but also to directly approach real professional tasks. The creation of 360° video promotes the development of critical thinking, creative abilities and technical skills in working with equipment and software, which are important components of professional competence. The practical experience of creating virtual tours using 360° video technology in educational projects has shown that this approach in the educational process is extremely effective. On the one hand, students became acquainted with one of the most relevant modern immersive technologies through their own practical experience. On the other hand, the developed methodology for creating 360° video tours has come in handy for other students who can create their own exciting projects. And finally, the created 360° video tour is not just another educational task, it is a real product that is used in practice.

Prospects for further scientific research are seen in the study of other aspects of 360° video development and the possibilities of using this immersive technology in higher education. In particular, it is planned to continue creating 360° videos to enrich the educational environment with high-quality immersive content: video tours shot at real objects, classrooms, university laboratories, at production facilities of stakeholders, as well as video content about the functioning of complex and hard-to-reach objects (inside airplanes, engines, other aircraft systems, etc.). It is also important to continue work on the development of methodological recommendations for their use of 360° video in the educational process. A special potential is seen in the creation of virtual excursions and tours in 360° format, which will allow students to gain practical skills and feel themselves in the conditions of real professional activity, even while being in the classroom.

Declaration on Generative AI: The authors have not employed any Generative AI tools.

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A model for improving the accuracy of educational content created by generative AI

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Abstract

Advancements in artificial intelligence (AI) are reshaping education, enabling personalized and adaptive learning experiences, yet ensuring the reliability of AI-generated content remains a critical challenge. This study addresses this gap by developing a system for text processing and factual claims verification, focusing on extracting factual claims, retrieving evidence from authoritative sources, verifying content, and rewriting it to ensure accuracy while maintaining pedagogical effectiveness. The system is designed to complement manual peer review processes by providing detailed annotations and evidence-based notes related to facts retrieved from different sources. The proposed system employs a multi-layered approach to content verification. At its core, it focuses on three key processes: (1) extracting and refining factual claims from text using sophisticated natural language processing techniques, (2) retrieving and analyzing evidence from multiple authoritative sources, and (3) verifying and rewriting content that will be proposed as a hint to ensure accuracy while maintaining pedagogical effectiveness. It integrates prompt engineering, multi-stage evidence analysis, different source information retrieval, and vector-based embeddings to get and classify evidence as supporting, contradicting, or neutral, using weighted credibility scoring and a proposed decision certainty level for each verification outcome. By employing a multi-layered approach, the system offers a practical and scalable solution for enhancing AI-generated content verification, paving the way for reliable applications in education and organizational knowledge management, and enabling educators and content creators to make informed decisions about content revision.

Keywords

generative AI, education content creation, prompt engineering, factual validation, model hallucinations, verify-and-edit frameworks

CEUR-WS.org/Vol-3918/paper372.pdf

1. Introduction

Artificial intelligence (AI) advancements are reshaping every facet of life, with education standing at the forefront of this transformation [1, 2]. By integrating subject matter experts (SMEs) directly into the process, AI can potentially enhance the accessibility, quality, and relevance of learning materials in transformative ways. Large language models (LLMs) may ensure tailored and up-to-date educational materials by generating high-quality content that evolves with feedback [3]. AI further personalises learning by adapting to individual needs, such as dynamically adjusting programming exercises' complexity and providing immediate feedback [4, 5]. However, alongside this promise comes a critical challenge: ensuring the depth, reliability, and correctness of AI-generated content.

This study approaches education from the perspective of organisational needs, where agility and alignment with evolving trends are paramount. Unlike traditional academic institutions, which often retain historical materials to support foundational knowledge [6, 7], organisations must rapidly produce and update training materials to remain competitive in fast-paced industries. However, the established model for content development—where learning and development (L&D) professionals serve as intermediaries between SMEs and learners—often struggles to meet these demands. While ensuring pedagogical rigour, this process is plagued by lengthy development timelines, high costs, and outdated

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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

materials due to iterative feedback loops and disconnected workflows. Recently, many organisations have shifted to a model where SMEs create learning materials directly, bypassing the need for L&D intermediaries. While this approach allows for faster development and greater alignment with real-time organisational needs, it introduces significant challenges. SMEs, though experts in their fields, often lack instructional design expertise, which can result in unstructured or overly dense content that lacks pedagogical clarity. Additionally, SME-created materials may fail to account for diverse learner needs, leading to inconsistencies in quality and engagement. Without the support of L&D professionals, these materials may fail to provide a cohesive learning experience [8].

Recent advancements in generative AI offer a powerful alternative to L&D support. These tools can transform raw SME input into structured, learner-focused content, acting as virtual instructional designers. Despite these innovations, the risks of bias, inaccuracies, and ethical concerns remain significant. Addressing these challenges is vital to harnessing the full potential of AI in education [9, 10].

The primary objective of this research is to develop a system for processing user-provided text and flagging inaccuracies while minimising biases and ensuring the reliability of content, including AI-generated content. This objective is critical to addressing the challenges posed by inaccuracies and inconsistencies and reducing the need for extensive manual reviews.

2. Theoretical background and related works

Integrating artificial intelligence (AI) in education has reshaped traditional paradigms, introducing adaptive learning environments, enhanced accessibility, and real-time content personalisation. AI systems, such as intelligent tutoring tools and automated assessment platforms, have demonstrated the potential to foster equitable education by addressing diverse learner needs. Chiu et al. [11] emphasise the transformative impact of AI-driven adaptability in tailoring educational materials to individual learning contexts. The role of LLMs, including GPT-based systems, has been pivotal in this transformation. These models can generate dynamic course content, provide personalised instruction, and offer instant feedback, fulfilling roles such as tutors, mentors, and collaborators [12]. Despite these advancements, there remain challenges in aligning AI tools with pedagogical goals, as highlighted by Kasneci et al. [13], who warn of biases and inaccuracies in AI-generated content.

SMEs play a crucial role in enriching educational content with domain-specific knowledge, yet their contributions often lack pedagogical structure when instructional design principles are not applied [6, 8, 14]. Generative AI offers a solution by acting as a virtual instructional designer, reorganising SME inputs into structured, learner-centred materials [3]. Nazar et al. [15] illustrate how tools like CourseGPT facilitate the learning process by providing real-time, course-specific support to students, ensuring consistency and alignment with educational goals. Moreover, generative AI enhances personalisation by adapting content difficulty to learner proficiency and providing instant feedback mechanisms, as demonstrated in automated programming exercises [4]. However, the absence of oversight can lead to unstructured and ineffective content, necessitating collaborative frameworks where SMEs and AI systems work together to achieve pedagogical soundness, content richness and accuracy [3].

Adopting generative AI in education has risks, including biases in training data, content inaccuracies, and model hallucinations. These concerns are compounded by the tendency of AI systems to produce stylistically convincing but factually erroneous outputs [9, 16, 17].

Tonmoy et al. [17] have developed a comprehensive taxonomy of hallucination mitigation techniques, categorising methods into two primary domains: prompt engineering and model development. Prompt engineering encompasses methods such as retrieval-augmented generation (RAG), which integrates external knowledge sources before, during, and after generation to enhance output grounding. Specific subcategories like the Decompose-and-Query Framework and EVER Framework employ iterative validation during generation to resolve complex reasoning challenges, while post-generation tools such as RARR retrofit outputs for improved factual accuracy. Model development strategies introduce architectural innovations, such as Context-Aware Decoding and faithfulness-based loss functions, to

align AI outputs with verified truths. Additionally, supervised fine-tuning techniques incorporate counterfactual datasets and knowledge graphs to strengthen model fidelity.

Similarly, Huang et al. [9] identify core issues such as insufficient domain-specific data and over-reliance on incomplete training corpora as major contributors to AI inaccuracies. These limitations often result in hallucinations that can be categorised into factuality and faithfulness types. Factuality hallucinations occur when outputs conflict with known truths or fabricate unverifiable information, while faithfulness hallucinations involve deviations from input instructions, contextual misalignments, or logical errors. Detection approaches such as factuality, and faithfulness validation employs fact-checking, uncertainty estimation, and QA-based systems, supported by benchmarks like TruthfulQA and HaluEval, to rigorously evaluate AI outputs. Mitigation strategies span data-level interventions, such as filtering misinformation during training, to advanced inference-level techniques, including constrained sampling and logical consistency checks, thereby addressing these multifaceted challenges. Broader societal implications are explored in "Promises and challenges of generative artificial intelligence for human learning" [16], which underscores equity and ethical transparency as critical factors in the deployment of AI in education.

Considering these risks, ensuring the reliability of AI-generated materials necessitates robust, multi-layered validation frameworks. Current gaps in these processes highlight the importance of SME involvement in verifying content accuracy and contextual relevance [3]. Complementing these efforts, Shamsujjoha et al. [18] advocate for a layered runtime guardrail approach inspired by the Swiss Cheese Model, wherein distinct defensive layers tandem to intercept and correct errors at multiple stages. This model emphasises the importance of redundancy and multifaceted defences, ensuring that vulnerabilities in one layer are mitigated by the following.

Dong et al. [19] extensively reviews existing guardrail solutions, highlighting tools like Llama Guard, Nvidia NeMo, and Guardrails AI. Llama Guard demonstrates adaptability by fine-tuning specific taxonomies but depends on LLM understanding for predictive accuracy. Nvidia NeMo incorporates vector-based embeddings and KNN for content moderation and hallucination prevention. At the same time, Guardrails AI uniquely employs XML-based RAIL specifications to define output quality guarantees, including automated error correction. Despite their utility, these solutions share common weaknesses, such as lacking generalisation and holistic multi-requirement designs, which underscores the need for more robust methodologies. Dong also identifies technical challenges, particularly unintended responses, which are detected through adversarial prompt testing and mitigated via adversarial training, safety reinforcement, and input/output rephrasing. Fairness remains a critical issue, with biases categorised into gender, cultural, and dataset origins. Protective measures, including fine-tuning and fairness-driven prompt engineering, are essential but require continuous learning and diversification of datasets. Privacy concerns, such as PII leakage, are addressed through differential privacy methods and personalised watermarking to ensure ownership and confidentiality. Hallucinations pose significant risks; detection strategies like self-consistency checks and external validations are complemented by protective measures such as retrieval-augmented generation and Verify-and-Edit frameworks [20]. These approaches balance robustness and adaptability, integrating rigorous software development life cycles and Pareto optimisation [19] for practical guardrail implementations.

3. Methods

The system was developed to process user-provided text, perform factual verification, and generate revisions where inconsistencies were identified. Building on established methodologies [15, 17, 20], the workflow incorporated multi-stage processing, structured claim extraction, evidence classification, and revision strategies. Prompt engineering techniques were employed, including prompt tuning with prompt chaining and multiple stages of results refinement. Most importantly, verification occurs after generation, meaning that the system receives and analyses any text. Decisions are made based on the retrieved information from various sources, including vectorised documents. The design emphasised adherence to factual accuracy while minimising stylistic alterations.

Testing was conducted using articles that sometimes included altered factual information to evaluate the system's ability to detect inaccuracies. Purely opinion-driven texts were excluded to ensure the dataset's alignment with the system's verification scope.

The input text is segmented into paragraphs and sentences. Next, claims are extracted from each sentence and then refined on the whole paragraph level to remove duplicates and improve the context for already-created claims.

Claims extraction prompt:

```
Extract all factual claims from the given text. A factual claim is any
statement that asserts something as a fact and can be verified.
Guidelines:
1. The 'claim_text' should distill the factual assertion while preserving
its meaning. Remove unrelated phrases or context.
2. The 'original_text' must exactly match the corresponding part of the
input text from which the claim was derived.
3. Each claim must contain only 1 factual information and enough context to
be unambiguous and easy to search, with context information, specific dates,
names, and people etc.
4. The claim must question single fact, not multiple facts, so that it's
easy to search but have enough context to be unambiguous.
6. Select a particular part of the original text when referencing it, not
the entire sentence
7. Do not include opinions, speculative statements, or rhetorical questions
as claims.
8. If there is ambiguity in the claim, provide the most concise and accurate
interpretation.
9. Ensure claims are extracted accurately, even if they are embedded in
longer sentences.
```

Then, the system retrieves evidence from external Google using Google Custom Search, Wikipedia, and a vector store for each claim. Evidence snippets are individually classified as Supporting, Contradicting, or Neutral based on relevance, which the model itself determines. Also, the model is instructed to output a credibility score based on the website on which the material was found. Irrelevant or low credibility are filtered out. Classification utilises chain-of-thought (CoT) reasoning, wherein the LLM processes claims and evidence incrementally to facilitate nuanced judgments.

Evidence analysis prompt:

```
Evaluate the relationship between the given claim and the provided evidence.
For each claim, determine whether the evidence supports, contradicts, or is
neutral to the claim.
Criteria for Decision:
- {DecisionClaimEnum.supporting}: Evidence explicitly affirms the claim
with no ambiguity.
- {DecisionClaimEnum.contradicting}: Evidence explicitly denies or disputes
the claim with no ambiguity.
- {DecisionClaimEnum.neutral}: Evidence is unrelated, ambiguous, or
insufficient to affirm or deny the claim.
Additionally, assess the credibility of the source using the following
scale:
- 1.0: Peer-reviewed resources (e.g., white papers, academic journals)
- 0.8: Crowd-sourced resources with robust moderation (e.g., Wikipedia)
- 0.6: Reputable news outlets and well-known publications
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- Below 0.6: Sources with questionable credibility or lack of verification
The result should include:
1. Decision: '{DecisionClaimEnum.supporting}', '{DecisionClaimEnum.
contradicting}', or '{DecisionClaimEnum.neutral}'
2. Source Credibility: A float value between 0 and 1, as defined above
3. Extract key phrases from the evidence that support the decision.
4. Provide a brief justification for the credibility score.
Additional Step:
- Relevance: Assess whether the evidence is contextually relevant to the
claim before determining the relationship.
- If evidence is irrelevant, set 'relevant' field to false and the decision
should default to '{DecisionClaimEnum.neutral}'
```

Classifications for each claim were aggregated by counting instances of supporting, contradicting, and neutral evidence. A weighted ratio method was employed to assess the certainty of each claim's correctness or incorrectness based on the credibility of evidence classified as supporting or contradicting. Each piece of evidence is assigned a credibility score (w_i) within a range of 0 to 1, reflecting the source's reliability (see evidence analysis prompt above). Certainty calculations consider the aggregated credibility and the total number of supporting (n_s) and contradicting (n_c) evidence items. The certainty that a claim is incorrect is calculated using the formula:

$$CertaintyIncorrect = \frac{ConTotal}{SupTotal + ConTotal} \tag{1}$$

where $SupTotal = \sum_{i=1}^{n_s} w_i$, the aggregated credibility of all supporting evidence; $ConTotal = \sum_{j=1}^{n_c} w_j$, the aggregated credibility of all contradicting evidence.

This ratio reflects the proportion of contradicting evidence relative to the total weighted evidence (supporting and contradicting). This score is compared against a predefined threshold (0.6 in this case) to determine if the claim should be flagged for revision if we are certain enough that it is incorrect.

When no supporting or contradicting evidence is provided ($n_s = 0$, $n_c = 0$), CertaintyIncorrect is set to 0, as the absence of evidence does not permit any judgment on correctness. Claims are not flagged for revision in this case.

When only supporting evidence is provided ($n_s > 0$, $n_c = 0$), certainty is determined by the average credibility of the supporting evidence:

$$CertaintyCorrect = \frac{SupTotal}{n_s} \tag{2}$$

If the average supporting credibility exceeds a threshold, the claim is considered correct and left unchanged; otherwise, it's considered uncertain. This does not trigger revisions due to the lack of contradicting evidence, which is the source of the revised version of the paragraph.

When only contradicting evidence is provided ($n_s = 0$, $n_c > 0$), the certainty that the claim is incorrect is determined by the average credibility of the contradicting evidence, similar to the previous case:

$$CertaintyIncorrect = \frac{ConTotal}{n_c} \tag{3}$$

However, this time, we also check if the threshold has not exceeded (0.6); if it does, we are confident enough to revise the paragraph text based on the contradicting evidence (use those as a source of truth).

It must be noted that this methodology filters out neutral evidence, which may lead to the loss of nuanced information. Incorporating a weighting factor for neutral evidence could improve robustness. Also, evidence with extremely high or low credibility scores (e.g., 1.0 or near 0) can disproportionately skew the results. Implementing a credibility cap or floor may mitigate this effect. Finally, the method switches from ratio-based certainty calculations (for mixed evidence) to average-based certainty in

edge cases (only supporting or contradicting), which can lead to perceived inconsistency in certainty interpretation.

4. Results

A simple web UI was developed to support better visualisation of results (the full listing is available here: https://github.com/Vidzhel/ai-fact-checker). The page has a field where the provided text is placed. Upon clicking "Verify", the whole text is sent for verification, which takes approximately 1 minute for up to 5 paragraphs of text (figure 1).

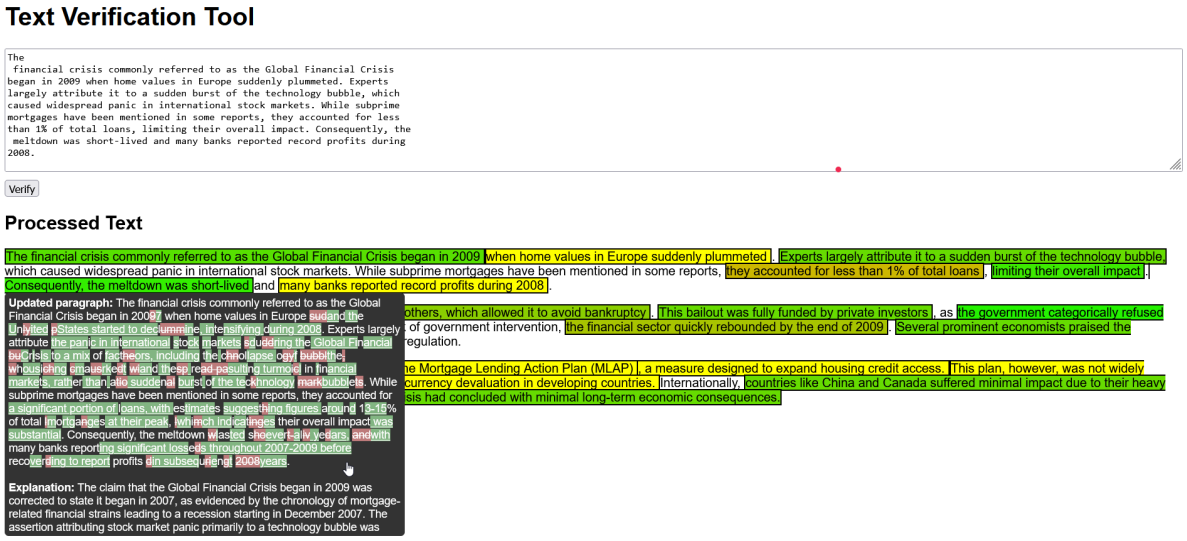


Figure 1: An example of the verification tool UI includes a field with inserted text and processed output that provides suggestions for different parts and a popup with details that are opened upon hovering highlighted parts of the text.

The processed text contains the same paragraphs with highlighted parts representing analysed parts of the text – claims. The colour of highlighting varies depending on the certainty of the decision (despite the paragraph being changed or not), where yellow indicates that the provided evidence seems to support the claim, and green indicates that the evidence is very likely to support the claim (basically gradient based certainty level ranging from 0.5 to 1). If the certainty level is below 0.5 – the highlighting will be red, indicating uncertainty. The highlighted parts can have either a black or blue border colour, indicating that the piece was or wasn't edited respectively.

Upon hovering over a highlighted part, a popup shows all the details related to the claim. Revised paragraphs start with the difference between original and revised paragraphs, and an explanation of the changes is summarised below. Then, there are details related to the certainty of the decision – the score and aggregated evidence counts. After that, a list of evidence is specified, each having the link, credibility level (with an explanation of the decision), a snippet of text used, a summary of findings related to the claim and classification (supporting, neutral, contradicting). This helps the reviewer make an informed decision [21].

Shortened example of details shown upon hovering over the highlighted part that was rewritten:

```
Updated paragraph: The financial crisis commonly referred to as the Global
Financial Crisis began in 2007 when home values in Europe  and the United
States started to decline, intensifying during 2008. Experts largely attribute
the panic in international stock markets during the Global Financial Crisis
to a mix of factors, including the collapse of the housing market and the
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resulting turmoil in  financial markets, rather than a sudden burst of the
technology bubble. While subprime mortgages have been mentioned in some
reports, they accounted for a significant portion of loans, with estimates
suggesting figures around 13-15% of total mortgages at their peak, which
indicates their overall impact was substantial. Consequently,  the meltdown
lasted several years, with many banks reporting significant losses throughout
2007-2009 before recovering to report profits in subsequent years.

Explanation: The claim that the Global Financial Crisis began in 2009 was
corrected to state it began in 2007, as evidenced by the chronology of mortgage-
related financial strains leading to a recession starting in December 2007. The
assertion attributing stock market panic primarily to a technology bubble was
revised to reflect the documented role of the housing market collapse and broader
financial crisis. The claim about subprime mortgages being less than 1% was
adjusted to acknowledge their substantial impact, aligning with evidence that
they represented a significant portion of lending. Lastly, the characterization
of the crisis as short-lived was corrected to acknowledge its prolonged effects,
lasting from 2007 into 2009.

Certainty: 0.87 - Based on gathered data - decision seems to be very likely
correct (whether claim was altered or not);
Supporting: 6 - Contradicting: 0 - Neutral: 1
Source: https://www.federalreservehistory.org/essays/subprime-mortgage-crisis
Cridability: 1 - The source is a reputable, peer-reviewed resource from the
Federal Reserve, which provides credible historical context and analysis.
Snippet: The expansion of mortgages to high-risk borrowers, coupled with
rising house prices, contributed to a period of turmoil in financial
markets that lasted from ...
Evidence: expansion of mortgages to high-risk borrowers...contributed to
a period of turmoil in financial markets
Classification: Supporting

Source: https://en.wikipedia.org/wiki/2007%E2%80%932008_financial_crisis
Cridability: 0.8 - The source is Wikipedia, a crowd-sourced resource with
robust moderation, making it a credible source for general information.
Snippet: The 2007–2008 financial crisis, or the global financial crisis
(GFC), was the most severe worldwide economic crisis since the 1929 Wall
Street crash that began the Great Depression. Causes of the crisis
included predatory lending in the form of subprime mortgages to low-income
homebuyers and a resulting ... in the 2010s European debt crisis.
Evidence: Causes of the crisis included predatory lending in the form of
subprime mortgages to low-income homebuyers
Classification: Supporting
```

5. Discussion

The outlined method offers a clear and practical framework for extracting, verifying, and refining claims, prioritising simplicity and effectiveness. Combining prompt engineering with a multi-stage evidence analysis process, the system consistently identifies claims within the text, retrieves relevant evidence, and refines results, making the review process more straightforward. Using prompt-chaining techniques, the system divides verification into smaller, manageable steps, such as clarifying ambiguous references

to entities, dates, or locations before retrieving evidence. This iterative approach incrementally improves accuracy and minimises errors caused by incomplete context.

While the system performs well in detecting factual inaccuracies, it faces some notable challenges. These include occasionally missing specific claims within a passage and failing to provide adequate context for specific claims. For instance, a statement like "the crisis significantly impacted the current economic situation" may lack explicit reference to timeframes or events, preventing effective retrieval of evidence. Resolving vagueness or insufficient detail issues is crucial for improving the system's reliability.

Addressing these shortcomings could involve fine-tuning the model with more varied and representative training examples. This would enhance its ability to recognise complex claims, define contextual boundaries, and retrieve evidence more precisely. Additionally, using vector embeddings, such as those from the text-embedding-3-small model, significantly boosts the system's capability for accurate evidence retrieval, particularly in specialised fields requiring alignment with specific terminology and context.

Another strength of the approach is its cost efficiency. By using a combination of GPT-4o-mini for generating completions and text-embedding-3-small for retrieval, the system processes approximately 3,000 pages (two million tokens) for just $0.50. Including a structured API further ensures robust performance by delivering machine-readable outputs validated against schemas. This consistency simplifies subsequent verification and refinement while reducing the risk of errors in output formatting.

6. Conclusions

This study presents a efficient approach for processing and verifying user-provided text, focusing on fact-checking provided text with evidence extracted from various sources. The system balances simplicity and performance by integrating embeddings for domain-specific retrieval and prompt-engineered reasoning techniques, making it a promising tool for real-world applications. The proposed system effectively extracts claims, retrieves relevant evidence, and classifies evidence to refine text based on credibility-weighted thresholds, allowing it to either prove fact correctness or mark and suggest an update for inaccurate text parts.

Despite these strengths, limitations remain. The system occasionally struggles to handle ambiguous claims or claims lacking sufficient context, complicating evidence retrieval and verification. Addressing these issues through fine-tuning can significantly enhance the system's contextual understanding and precision. Also, including more test data would be beneficial.

Compared to similar tools, this system stands out for its emphasis on combining affordability with a structured approach to ensure consistent results. Unlike generic models prioritising breadth over domain specificity, the embedding-based retrieval method employed here enhances precision, particularly in specialised fields.

Overall, this study highlights the potential of combining simple yet powerful techniques to address text verification and content refinement challenges. The findings demonstrate that a structured, scalable approach can provide reliable results while opening avenues for further refinement and adoption in diverse applications. Researchers and developers are encouraged to explore and refine this system in real-world settings, ensuring its full potential is realised across domains.

Declaration on Generative AI: During the preparation of this work, the authors used GPT-4o in order to: Generate literature review, Abstract drafting, Content enhancement. After using this service, the authors reviewed and edited the content as needed and takes full responsibility for the publication's content.

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Implementing MLOps practices for effective machine learning model deployment: A meta synthesis

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Abstract

The successful deployment of machine learning (ML) models in production environments remains a significant challenge despite advancements in ML algorithms and model development. MLOps, a set of practices that combines machine learning and DevOps principles, has emerged as a promising approach to address this challenge. This paper presents a meta-synthesis of systematic reviews to provide a comprehensive understanding of MLOps practices, tools, and challenges for effective ML model deployment. The meta-synthesis was conducted following Chrastina's [1] methodology and included three systematic reviews and one review of MLOps products and providers. The meta-synthesis identified key MLOps principles, such as automation, reproducibility, collaboration, continuous learning, and data governance. It also revealed the main stages of the MLOps workflow, including data collection and processing, model development and training, deployment, monitoring, and retraining. Various frameworks and architectures that facilitate MLOps implementation were discussed, such as open-source platforms, cloud computing platforms, containerization, and container orchestration. The study highlighted the main features offered by MLOps tools, including automation, experiment tracking, versioning, monitoring, and model deployment. The most common methods of deploying ML models in production environments were identified as the use of container technologies, cloud platforms and services, and deployment of models as web services. The meta-synthesis also discussed the importance of adapted software development maturity models for assessing the maturity level of MLOps processes in organizations. Furthermore, the paper emphasized the critical roles and responsibilities involved in ML model operationalization activities, such as data scientists, data engineers, DevOps engineers, and domain experts. The main challenges encountered when deploying ML models in production environments were discussed, including managing the model lifecycle, ensuring scalability and performance, monitoring and maintaining models in real-world conditions. Open issues and challenges in MLOps were also identified, such as the need to develop standards and best practices, ensure interpretability and responsible use of models, and effectively manage data. The findings of this meta-synthesis can guide organizations in adopting MLOps practices to improve the efficiency, reliability, and scalability of their ML model deployments.

Keywords

MLOps, machine learning, model deployment, meta-synthesis, systematic review, DevOps, automation, monitoring, versioning, scalability

1. Introduction

Machine learning (ML) has become an increasingly important technology, finding applications in various domains such as finance, healthcare, manufacturing, retail, and more [2, 3, 4]. The successful deployment of ML models in production environments is crucial for organizations to reap the benefits of this technology. However, despite significant progress in developing ML algorithms and models, their effective deployment in production environments remains a challenging task [5, 6]. This is due to several factors, such as the need for scalability, reproducibility, security, and reliability of models, as well as the complexity of integrating development and operation processes.

AREdu 2024: 7th International Workshop on Augmented Reality in Education, May 14, 2024, Kryvyi Rih, Ukraine
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CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

CEUR-WS.org/Vol-3918/paper404.pdf

To address these challenges, the methodology of MLOps (Machine Learning Operations) has emerged, aiming to apply DevOps principles and practices to the processes of developing and deploying ML models [7, 5]. MLOps covers a wide range of practices, such as automation of ML pipelines, versioning of data and models, monitoring of model performance, experiment management, and more [7, 6]. Studies show that applying MLOps practices can significantly improve the efficiency and reliability of deploying ML models in production environments [5, 6].

However, despite significant interest in MLOps from both researchers and practitioners, there are still gaps and unresolved issues in this field. In particular, there are no generally accepted standards and best practices for implementing MLOps, the issues of integrating MLOps with other approaches (DataOps, ModelOps, AIOps, etc.) are insufficiently explored, and there is a need to develop new tools and platforms to automate MLOps processes [7, 5, 6].

This paper aims to address the relevant problem of defining and analyzing the MLOps practices needed for effective deployment of machine learning models. The basis for this work is the need to systematize and generalize knowledge about MLOps practices, as well as the need to develop recommendations for their implementation in organizations to improve the efficiency and reliability of deploying machine learning models in production environments.

The rest of the paper is organized as follows. Section 2 describes the methodology used for the meta-synthesis. Section 3 presents the results of the meta-synthesis, including the definition of MLOps, stages of the MLOps workflow, frameworks and architectures facilitating MLOps implementation, MLOps tools, features offered by MLOps tools, methods of deploying ML models, maturity models for assessing the level of automation, roles and responsibilities in ML model operationalization activities, challenges encountered when deploying ML models, open issues and challenges in MLOps, and opportunities and future trends in MLOps. Section 4 concludes the paper and outlines directions for future research.

2. Methodology

The meta-synthesis was performed according to Chrastina [1] in the following steps:

1. *Defining the research subject*: MLOps practices for effective model deployment.
2. *Identifying relevant sources*: systematic literature reviews [7, 5, 6] and a review of MLOps products and providers [8].
3. *Close examination* to determine the common time period, commonalities and differences in the aims, research questions, sources, inclusion, exclusion and quality criteria, MLOps definitions and stages.
4. *Determining the relationship between the works* by identifying and grouping key themes.
5. *Reciprocal translation of the results of different works* by defining common terminology, explaining contradictions in the results from different works, and generalizing the results from different works.
6. *Synthesis of results.*
7. *Expressing the synthesis.*

The meta-synthesis included three systematic reviews [7, 5, 6] and one review of MLOps products and providers [8]. The systematic reviews were selected based on a search in the Scopus database using the following query: `TITLE ( ( systematic OR review OR survey ) AND mlops )`. The review of MLOps products and providers [8] was included to provide additional insights into the practical aspects of MLOps implementation.

The meta-synthesis focused on the following key themes: MLOps definition, stages of the MLOps workflow, frameworks and architectures facilitating MLOps implementation, MLOps tools, features offered by MLOps tools, methods of deploying ML models, maturity models for assessing the level of automation, roles and responsibilities in ML model operationalization activities, challenges encountered when deploying ML models, open issues and challenges in MLOps, and opportunities and future trends in MLOps.

The results of the meta-synthesis were expressed in the form of a narrative synthesis, summarizing the key findings and insights from the included reviews. The synthesis aimed to provide a comprehensive understanding of MLOps practices, tools, and challenges for effective ML model deployment, as well as to identify open issues and future trends in this field.

3. Results

3.1. MLOps definition

Despite some differences in emphasis and formulations, all the reviews examined define **MLOps** as an **approach for managing, automating, and operationalizing the processes of developing, deploying, and maintaining machine learning models based on practices from software engineering and DevOps**. MLOps is a key component for the successful implementation of machine learning solutions in an industrial environment.

3.2. MLOps workflow stages

Despite different levels of detail and grouping, the reviews demonstrate overall consistency regarding the main stages of the MLOps workflow. These stages cover the entire lifecycle of machine learning models, from data collection and processing to deployment, monitoring, and retraining of models. Differences in the presentation of stages reflect different approaches to structuring and describing the MLOps workflow.

The main stages of the MLOps workflow identified in the reviews include:

- Data collection and processing: collecting, cleaning, transforming, and enriching data for training models.
- Model development and training: selecting algorithms, developing model architecture, training and validating models.
- Model evaluation and testing: evaluating model performance on test data, conducting reliability, security, and compliance tests.
- Model deployment: packaging models with required dependencies, deploying to target environments.
- Model monitoring and maintenance: tracking model performance, detecting and resolving issues, updating models as needed.
- Model lifecycle management: coordinating all stages of model development, deployment, and maintenance, ensuring compliance with regulatory requirements.

3.3. Frameworks and architectures facilitating MLOps implementation

There are many frameworks and architectural approaches that facilitate the implementation of MLOps, from open platforms and libraries to commercial solutions and cloud services. Key factors are support for automation, scalability, portability, and integration with existing systems and tools. The choice of appropriate frameworks and architectures depends on the specific requirements and constraints of the organization, as well as the maturity level of its MLOps processes.

The reviews highlight the following frameworks and architectures as key components of the MLOps ecosystem:

- Open-source platforms and frameworks, such as MLflow, Kubeflow, and TensorFlow Extended (TFX).
- Cloud computing platforms and services, such as AWS, Google Cloud, and Azure, for deploying and scaling MLOps solutions.
- Containerization (e.g., using Docker) and container orchestration (e.g., using Kubernetes) architectures for ensuring portability and scalability of MLOps solutions.

- Pipeline orchestration platforms, such as Apache Airflow, Jenkins, and Polyaxon.
- Specific frameworks and platforms, such as Kafka-ML and MLModelCI, for managing the lifecycle of ML models.

3.4. MLOps tools for building ML pipelines and model operationalization

There is a wide range of MLOps tools for building machine learning pipelines and operationalizing models, from open platforms such as MLflow to commercial solutions from cloud providers and specialized companies. The choice of specific tools depends on the needs and scale of the organization, as well as compatibility with the existing technology stack.

The reviews highlight the following popular MLOps tools:

- MLflow, a popular open-source platform for managing the lifecycle of ML models, experiments, and deployment.
- Cloud platforms from major providers, such as AWS SageMaker, Google Cloud AI Platform, and Azure Machine Learning, for operationalizing models.
- Containerization tools, such as Docker, and orchestration tools, such as Kubernetes, for deploying models.
- Other tools, such as Kubeflow, Polyaxon, Comet.ml, Kafka-ML, and MLModelCI, for managing pipelines and deploying models.
- Popular commercial MLOps platforms, such as Iguazio, Domino Data Lab, Comet, Valohai, and others.

3.5. Key features offered by MLOps tools

MLOps tools provide a wide range of features to support the machine learning model lifecycle, with a focus on automation, experiment tracking, versioning, monitoring, and model deployment. Some tools offer more specialized features, such as hyperparameter optimization or data management. The choice of a tool with an appropriate set of features depends on the specific needs and goals of the organization in the field of MLOps.

The reviews identify the following key features offered by MLOps tools:

- Experiment tracking and model versioning.
- Automation and orchestration of MLOps workflows, such as training and deployment pipelines.
- Monitoring of model performance and degradation in production environments.
- Data management features, such as data extraction, transformation, and monitoring.
- Support for various machine learning libraries and frameworks.
- Automated hyperparameter optimization and model testing.
- Integration with existing systems and support for collaborative work of teams.

3.6. Methods of deploying ML Models in production environments

The most common methods of deploying machine learning models in production environments are the use of container technologies, cloud platforms and services, and deployment of models as web services. The choice of a specific approach depends on the requirements for latency, scalability, and availability of models, as well as the existing infrastructure and ecosystem of tools in the organization.

The reviews describe the following key methods and aspects of deploying ML models:

- Deploying models using container technologies, such as Docker, which ensures model mobility and isolation.
- Deploying models in cloud environments using platforms and services from major providers, such as AWS, Google Cloud, and Azure.

- Deploying models as web services using REST API or other protocols to provide access to predictions in real-time.
- Using orchestration platforms (Apache Airflow, Jenkins, Kubeflow, MLflow, Polyaxon, Seldon Core, Valohai) for automated scaling and container management.
- Built-in deployment capabilities of some MLOps tools, such as MLflow, Kubeflow, and Kafka-ML.
- Deploying models not only in the cloud but also on edge devices using specialized frameworks, such as TensorFlow Lite and Core ML.
- The main stages and features of the ML model deployment process using CI/CD pipelines

3.7. Maturity models for assessing the level of automation in deploying ML models

All systematic reviews [7, 5, 6] indicate that the level of automation of MLOps processes is one of the key factors in assessing an organization's maturity in this area. Although the reviews do not provide a comprehensive description of MLOps maturity models, they emphasize the importance of assessing the level of automation in the processes of developing, testing, and deploying models as a key factor in an organization's maturity in this area. Adapting existing software development maturity models to the specifics of MLOps can be an effective approach to assessing and improving machine learning processes in an organization.

The reviews mention several maturity models for assessing the level of improvement in the machine learning solutions development process:

- The maturity model proposed by Amershi et al. [9], based on the Capability Maturity Model (CMM) and the Six Sigma methodology, which checks whether an activity: (1) has defined goals, (2) is consistently implemented, (3) is documented, (4) is automated, (5) is measured and tracked, and (6) is continuously improved.
- According to Dhanorkar et al. [10], organizations can be classified into three levels of maturity in developing machine learning solutions: (1) data-oriented, (2) model-oriented, (3) pipeline-oriented.
- Lwakatare et al. [11] describe five stages of development practices improvement: (1) a manual process driven by data science, (2) a standardized process of experimental-operational symmetry, (3) an automated ML workflow process, (4) integrated software development and ML workflow processes, and (5) an automated and fully integrated CD and ML workflow process.
- Akkiraju et al. [12] proposed an adaptation of the CMM model with the definition of five maturity levels for each assessed capability: (1) initial, (2) repeatable, (3) defined, (4) managed, and (5) optimizing.

3.8. Roles and responsibilities identified in ML model operationalization activities

Despite some differences in the detail of roles, the reviews examined recognize the need to involve professionals from various fields - software development, data engineering, machine learning, subject matter experts, and management - for the successful operationalization of machine learning models. Close collaboration and communication between these roles is critical for the implementation of MLOps practices in organizations.

The reviews identify the following key roles and responsibilities in ML model operationalization activities:

- Data scientists/ML scientists, who are responsible for developing, training, and experimenting with ML models.
- Data engineers/data providers, who are responsible for extracting, processing, transforming, and ensuring the quality of data for training models.
- DevOps engineers, ML/MLOps engineers, and software engineers, who are responsible for operationalizing models, automating deployment processes, creating pipelines, and managing environments.

- Managers, leadership, and business stakeholders, who define requirements for models regarding their deployment, make decisions, and support the MLOps strategy.
- Domain experts, who provide domain knowledge and participate in data labeling in specific domains.

Some reviews also mention additional roles, such as computational scientists/engineers, ML scientists/engineers, provenance specialists, application developers, and deployment leads, who have specific responsibilities in the MLOps process.

3.9. Challenges encountered when deploying ML models in production environments

The reviews demonstrate that deploying machine learning models in production environments is associated with a number of challenges, such as managing the model lifecycle, ensuring scalability and performance, monitoring and maintaining models in real-world conditions. Addressing these challenges requires a comprehensive approach that includes automating MLOps processes, selecting appropriate infrastructure, ensuring data security and privacy, and effective communication with business stakeholders.

The main challenges identified in the reviews include:

- The complexity of managing the machine learning model lifecycle, including versioning, tracking, and reproducibility of models and data, as well as the problem of ensuring the scalability and performance of models in real-world conditions with large volumes of data and requests.
- Challenges related to monitoring and maintaining models in a production environment, including detecting data drift and model performance degradation.
- Challenges related to integrating software development with the machine learning pipeline.
- Challenges related to ensuring data security and privacy when deploying machine learning models.
- The quality, availability, preparation, labeling, and integration of data from various sources is a significant challenge that requires a lot of time and resources, and the problem of interpreting and explaining the results of model operation to end-users and business stakeholders is highlighted.
- The gap between software engineering and machine learning skills - data scientists often do not understand the requirements of certain production environments, and software developers do not have sufficient machine learning skills.
- The effective distribution, parallelization, and orchestration of data and ML tasks.
- The diversity of computing infrastructure.

3.10. Open issues, challenges and particularities in MLOps

The reviews identify a number of open issues and challenges in MLOps, such as the need to develop standards and best practices, ensure interpretability and responsible use of models, and effectively manage data. The particularities of MLOps, such as the difference from traditional software development, the importance of the human factor, and the need to integrate knowledge from various fields, require consideration when implementing MLOps practices in organizations.

The main open issues and challenges in MLOps identified in the reviews include:

- The need to develop methods and tools to ensure interpretability, reproducibility, and responsible use of machine learning models in the context of MLOps.
- The importance of developing approaches to data management in MLOps, including ensuring data quality, privacy, and security.
- The need to develop and implement MLOps standards and best practices to ensure consistency and compatibility between different tools and platforms.

- The importance of the human factor in MLOps, including the need to ensure effective communication and collaboration between different roles and teams and to train qualified personnel with cross-functional skills in programming, data processing, and operational activities.

The reviews also highlight the following particularities of MLOps:

- MLOps must take into account the specifics of the machine learning model development process, which differs from traditional software development.
- MLOps should be considered in the context of the overall digital strategy of the organization and emphasize the need to align MLOps practices with business goals and needs.

3.11. Opportunities, future trends and fields of application of MLOps

The reviews outline a number of opportunities and trends in the development of MLOps, such as the creation of standardized platforms, application in the context of distributed learning, and integration with other approaches to data and model lifecycle management. Current and future areas of MLOps application include a wide range of industries, from finance and healthcare to IoT and natural language processing, indicating the significant potential impact of this approach.

The main opportunities and future trends in MLOps identified in the reviews include:

- The potential for the development of standardized MLOps platforms and tools that will simplify and accelerate the deployment of machine learning models in production.
- The prospects for integrating MLOps with other approaches, such as DataOps, ModelOps, and DevSecOps, to ensure comprehensive management of the machine learning model lifecycle.
- Significant opportunities for further academic research and development due to the fact that MLOps is still at an early stage.
- The expectation of an increase in demand for MLOps tools and platforms with the spread of artificial intelligence solutions.
- The emergence of new roles and competencies related to MLOps as the industry develops.
- Opportunities for applying MLOps practices in the context of distributed and federated model learning, which will allow efficient use of decentralized data.
- Involving business units and educating management on MLOps principles.
- The use of hardware platforms such as FPGA and IoT to improve performance and privacy.

The reviews identify the following current and future areas of MLOps application:

- Industries such as finance, healthcare, retail, marketing, and manufacturing, where machine learning models are already actively used to solve real business problems.
- The potential for applying MLOps in the field of IoT and edge computing, where machine learning models can be deployed on resource-constrained devices.
- 5G and 6G technologies, educational and scientific activities.
- Transport and logistics.

4. Conclusion

This paper performed a meta-synthesis of systematic reviews and a review of MLOps products and providers to summarize knowledge about implementing MLOps practices for effective deployment of machine learning models. The main findings obtained as a result of the meta-synthesis are as follows:

1. MLOps is an approach for managing, automating, and operationalizing the processes of developing, deploying, and maintaining machine learning models based on practices from software engineering and DevOps. MLOps is based on a set of principles, processes, and practices that ensure the effective development, deployment, and maintenance of machine learning models.

2. The main stages of the MLOps lifecycle include data collection and processing, model development and training, deployment, monitoring, and retraining.
3. Various frameworks and architectures are used to implement MLOps, such as open source platforms (MLflow, Kubeflow, TensorFlow Extended), cloud computing platforms (AWS, Google Cloud, Azure), containerization (Docker), and container orchestration (Kubernetes).
4. MLOps tools provide a wide range of features to support the machine learning model lifecycle, with a focus on automation, experiment tracking, versioning, monitoring, and model deployment.
5. The most common methods of deploying machine learning models in production environments are the use of container technologies, cloud platforms and services, and deployment of models as web services.
6. Adapted software development maturity models, such as CMM, can be used to assess the maturity level of MLOps processes in organizations.
7. Successful implementation of MLOps requires the involvement of professionals from various fields - software development, data engineering, machine learning, subject matter experts, and management.
8. The main challenges in deploying machine learning models in production environments are managing the model lifecycle, ensuring scalability and performance, monitoring and maintaining models in real-world conditions.
9. The open issues and challenges in MLOps are the need to develop standards and best practices, ensure interpretability and responsible use of models, effectively manage data, and integrate knowledge from various fields.
10. The main opportunities and trends in the development of MLOps are the creation of standardized platforms, application in the context of distributed learning, and integration with other approaches to data and model lifecycle management. Current and future areas of MLOps application include a wide range of industries, from finance and healthcare to IoT and natural language processing.

The meta-synthesis showed that MLOps is a promising approach for the effective deployment of machine learning models in production environments, which requires further research and development to address existing challenges and realize potential opportunities.

The results obtained have both theoretical and practical significance. The theoretical significance lies in the generalization and systematization of knowledge about MLOps practices necessary for the effective deployment of machine learning models. The practical significance of the results obtained lies in the possibility of their use by organizations to implement or improve MLOps processes in order to increase the efficiency and reliability of deploying machine learning models in production environments.

Further research may be aimed at developing detailed recommendations for the implementation of individual MLOps practices in organizations, creating new tools and platforms for automating and managing the lifecycle of machine learning models, as well as studying the effectiveness of applying MLOps practices in various industries and areas of machine learning model application.

Declaration on Generative AI: During the preparation of this work, the authors used Claude 3 Opus in order to: Text Translation, Abstract drafting. After using this service, the authors reviewed and edited the content as needed and takes full responsibility for the publication's content.

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