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Advancing educational resilience: Key insights and innovations from the XVII International Conference on Mathematics, Science, and Technology Education (ICon-MaSTEd 2025)

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Advancing educational resilience: Key insights and innovations from the XVII International Conference on Mathematics, Science, and Technology Education (ICon-MaSTEd 2025)

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Abstract. This paper presents a comprehensive review of the XVII International Conference on Mathematics, Science and Technology Education (ICon-MaSTEd 2025), held from May 14-16, 2025, at Kryvyi Rih State Pedagogical University, Ukraine. The conference, organized in a hybrid format, brought together over 100 attendees from 9 countries, showcasing cutting-edge research and innovations in educational practices amid global challenges. The review synthesizes key themes and findings from 31 selected papers across various domains, including Mathematics Education, Science Education, Computer Science Education, and Educational Technology. Notable trends include the increased integration of artificial intelligence and digital technologies in education, the development of 21st-century skills, and adaptive strategies for education in crises. Particular attention is given to studies addressing the unique educational challenges faced in Ukraine, demonstrating the resilience and innovation of educators and researchers in conflict-affected regions. The paper highlights significant contributions in areas such as online learning environments, visual thinking in mathematics, AI applications in mental health education, and the design of university digital ecosystems. The proceedings also commemorate the 90th anniversary of Professor Arnold Yukhymovych Kiv, co-founder of ICon-MaSTEd and a distinguished physicist whose contributions to solid state physics and educational innovation have shaped generations of scientists and educators.



1. Introduction

The XVII International Conference on Mathematics, Science, and Technology Education (ICon-MaSTEd 2025) represents a pivotal moment in the evolution of educational discourse, particularly as it convened amid unprecedented global challenges. Held from May 14-16, 2025, at Kryvyi Rih State Pedagogical University in Ukraine, this conference demonstrated the remarkable resilience and innovative capacity of the international educational community in addressing the complex demands of 21st-century learning environments. The hybrid format of the conference, necessitated by ongoing geopolitical tensions and the legacy of pandemic-induced transformations, brought together over 100 participants from 9 countries, including Ukraine, Norway, Israel, Greece, Philippines, Germany, Kazakhstan, Poland, and Slovakia, showcasing the truly global nature of contemporary educational challenges and solutions.

Since its inception in 2001, ICon-MaSTEd has established itself as a premier platform for researchers, educators, policymakers, and practitioners to exchange cutting-edge research findings and innovative pedagogical approaches in mathematics, science, and technology education (figure 1) [1–6]. The 2025 edition marks a particularly significant milestone, as it not only continues this tradition of scholarly excellence but also addresses the urgent need for educational adaptation in crisis situations. The conference's organization by the Academy of Cognitive and Natural Sciences (ACNS) in collaboration with Kryvyi Rih State Pedagogical University, the Institute for Digitalisation of Education of the NAES of Ukraine, and Ben-Gurion University of the Negev, underscores the importance of international cooperation in advancing educational innovation during times of adversity.

The primary objective of this paper is to present a comprehensive review of the key findings, innovations, and emerging trends discussed at ICon-MaSTEd 2025. Through the analysis of 31 carefully selected papers from a total of 71 submissions, this review synthesizes the collective wisdom of the conference participants across diverse domains including Mathematics Education, Science Education, Computer Science Education, and Educational Technology. Particular emphasis is placed on three overarching themes that permeated the conference proceedings: the integration of artificial intelligence and digital technologies in educational practices, the development of adaptive strategies for education in crisis contexts, and the cultivation of essential 21st-century competencies among learners.

The significance of this conference extends beyond traditional academic discourse. As educators worldwide grapple with the dual challenges of technological transformation and geopolitical instability, ICon-MaSTEd 2025 provides crucial insights into how educational systems can maintain quality and continuity under extraordinary circumstances. The conference highlighted innovative solutions ranging from augmented reality applications for laboratory work conducted in bomb shelters to AI-powered curriculum recommendation systems that personalize learning pathways in resource-constrained environments. These innovations are not merely temporary responses to crisis situations but represent fundamental advances in educational methodology that will continue to benefit learners long after current challenges have passed.

The conference's detailed program and session information was made available to all attendees

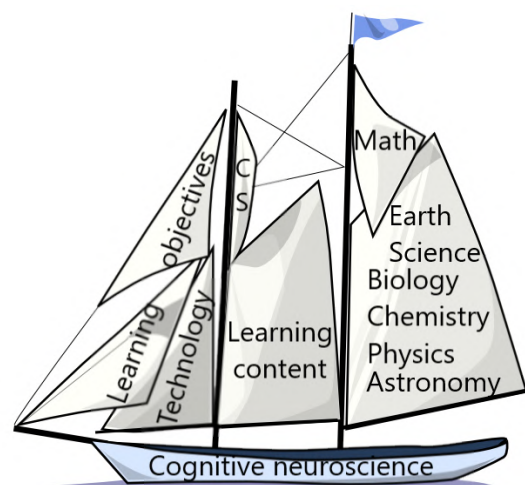


Figure 1. ICon-MaSTEd logo.

on the official website: <https://icon-masted.easyscience.education/2025/>. Additionally, to ensure wider accessibility and reach, video recordings of all talks were uploaded to the *Not So Easy Science* YouTube channel (<https://www.youtube.com/@NotSoEasyScience>).

The structure of this paper follows the thematic organization of the conference itself, with dedicated sections examining contributions in Mathematics Education, Physics Education, Science Education, Computer Science Education, and Educational Technology. Each section synthesizes the key findings from multiple presentations, identifying cross-cutting themes and highlighting particularly innovative approaches. Special attention is given to studies that address the unique educational challenges faced in Ukraine, demonstrating how adversity can catalyze innovation and foster the development of resilient educational ecosystems. Through this comprehensive review, we aim to provide educators, researchers, and policymakers with actionable insights that can inform educational practice and policy development in both crisis and normal circumstances.

2. A tribute to Professor Arnold Yukhymovych Kiv on his 90th anniversary

The XVII International Conference on Mathematics, Science and Technology Education (ICon-MaSTEd 2025) holds special significance as it coincides with the 90th anniversary of its co-founder, Professor Arnold Yukhymovych Kiv (Arik E. Kiv), a distinguished physicist whose remarkable career has profoundly influenced both scientific research and educational innovation across multiple continents. Born on July 28, 1935, in Odesa, Ukraine, Professor Kiv's life journey exemplifies the transformative power of scientific dedication and educational vision, even in the face of historical upheavals and geopolitical challenges.



Figure 2. Professor Arnold Yukhymovych Kiv.

Professor Kiv's academic journey began at Odessa State University, where he graduated in 1959 with a degree in physics. His early career (1960-1972) at the Academy of Sciences of the Uzbek SSR in Tashkent saw him serving as a research scientist at the Institute of Nuclear Physics and Electronics, while simultaneously fulfilling duties as Scientific Secretary of the Division of Physical and Mathematical Sciences. During this formative period, he also served as Scientific Secretary of the Coordination Council for Peaceful Use of Atomic Energy (1962-1970) and taught at the Tashkent Polytechnic Institute, establishing the interdisciplinary approach that would characterize his entire career.

The years 1972-1983 marked a transformative period for both Professor Kiv and Kryvyi Rih State Pedagogical Institute (now University), where he served as Head of the Department of Physics. His leadership elevated the institution from regional to national and international prominence in solid state physics research. Under his guidance, the department developed a unique atmosphere of collaboration, mutual respect, and rigorous scientific standards that continues to inspire researchers today. His establishment of the International Scientific School "Radiation Electronics of Solid State" during this period created a vital scientific center that has, for over half a century, maintained significant influence on scientific and pedagogical activities in Ukraine and beyond.

Following his tenure at Kryvyi Rih, Professor Kiv joined South Ukrainian National Pedagogical University named after K. D. Ushynsky in Odesa (1983), where he served as

Head of the Department of Theoretical Physics and later the Department of Physical and Mathematical Modeling. His international career included a distinguished professorship at Ben-Gurion University of the Negev, Israel (1998-2007), where he continued his groundbreaking research while fostering international scientific collaboration. Since 2022, he has served as Professor in the Department of Innovative Technologies and Methods of Teaching Natural Sciences at South Ukrainian National Pedagogical University.

Professor Kiv's scientific contributions have fundamentally advanced our understanding of solid state physics, particularly in radiation effects in semiconductors. He developed the theory of subthreshold radiation effects and radiation-stimulated diffusion in semiconductors, demonstrated the influence of low-energy radiation on structural disorders in electronic materials and devices, and established mechanisms of natural aging in materials while developing methods for determining the operational lifespan of materials and devices. His research interests span solid state physics, microelectronics, photopolymerization, defect creation, and stimulated diffusion, with a remarkable h-index of 26 (22 in the last six years alone), demonstrating the continuing relevance and impact of his work.

The co-founding of ICon-MaSTEd represents one of Professor Kiv's most enduring contributions to education. His vision of a platform for interdisciplinary dialogue in mathematics, science, and technology education has fostered international collaboration for over two decades. The conference has become a crucial venue for addressing contemporary educational challenges, from the integration of digital technologies to crisis-responsive pedagogical innovations. His leadership has ensured that ICon-MaSTEd remains at the forefront of educational innovation, adapting to changing global circumstances while maintaining its commitment to scientific excellence.

Professor Kiv's exceptional contributions have been recognized through numerous prestigious awards, including the State Prize of the Ukrainian SSR in Science and Technology (1983), the State Prize of the USSR (1988), and a Certificate from the President of the National Academy of Sciences of Ukraine for achievements in scientific research (2010). He has been honored as an Excellent Worker of Public Education of the Ukrainian SSR and a Honored Worker of Education of Ukraine. His international recognition includes membership in the scientific councils of Prague and Riga Universities, designation as a Soros Professor, and membership on editorial boards of multiple scientific journals.

As we celebrate Professor Kiv's 90th anniversary, we acknowledge not only his scientific achievements but also his profound influence on generations of physicists, educators, and researchers. His students, now leading scientists and educators worldwide, continue to advance the traditions of rigorous scientific inquiry and innovative educational practice that he established. The scientific school he founded at Kryvyi Rih has produced numerous doctoral and candidate degree holders who carry forward his legacy of excellence in research and education.

Professor Kiv's career demonstrates that true scientific leadership transcends disciplinary boundaries and geographical limitations. His ability to maintain productive research collaborations across political divides, his commitment to nurturing young scientists, and his vision for technology-enhanced education have created lasting impacts that extend far beyond his immediate sphere of influence. Even at 90, Professor Kiv continues to inspire through his unwavering dedication to science and education, serving as a living example of how passion for knowledge and commitment to human development can overcome any obstacle.

The ICon-MaSTEd 2025 conference, convening under challenging circumstances due to ongoing regional conflicts, embodies the resilience and determination that Professor Kiv has exemplified throughout his career. His life's work reminds us that science and education are universal human endeavors that transcend political boundaries and unite us in our common pursuit of knowledge and understanding. As we review the proceedings of this conference, we do so with deep appreciation for the foundation that Professor Kiv has laid and the pathways

he has opened for future generations of scientists and educators.

On behalf of the entire ICon-MaSTEd community, Kryvyi Rih State Pedagogical University and South Ukrainian National Pedagogical University, and the international scientific community, we extend our heartfelt congratulations to Professor Arnold Yukhymovych Kiv on his 90th anniversary. We wish him continued good health, happiness, and the joy of seeing his scientific and educational legacy flourish in the work of those he has inspired. May his remarkable journey continue to illuminate the path for scientists and educators worldwide.

3. ICon-MaSTEd 2025 organizers and partners

The XVII International Conference on Mathematics, Science and Technology Education (ICon-MaSTEd 2025) was organized through a collaborative effort of leading educational and research institutions, reflecting the conference's commitment to fostering international cooperation and interdisciplinary dialogue in educational innovation.

3.1. Primary organizer

The Academy of Cognitive and Natural Sciences (ACNS, <https://acnsci.org>) served as the primary organizing body for ICon-MaSTEd 2025. Established as a non-governmental organization dedicated to advancing research and education in cognitive and natural sciences, ACNS embodies the interdisciplinary spirit that has characterized ICon-MaSTEd since its inception. The Academy's mission encompasses:

- Fostering cutting-edge research initiatives in cognitive and natural sciences through collaborative networks of researchers across disciplines and institutions
- Organizing international conferences, workshops, seminars, and training programs that facilitate knowledge exchange and professional development
- Publishing high-quality scientific journals, conference proceedings, and scholarly works that disseminate research findings to the global academic community
- Supporting researchers' professional development through mentorship programs, research grants, and career advancement opportunities
- Protecting and advocating for researchers' rights, academic freedom, and ethical standards in scientific inquiry
- Building bridges between academic research and practical applications in education, industry, and society

ACNS's publishing portfolio includes several Diamond Open Access journals that align with ICon-MaSTEd's educational mission, most notably *Educational Technology Quarterly*, *Educational Dimension*, and *Science Education Quarterly*. These publications provide year-round platforms for disseminating research presented at ICon-MaSTEd and related conferences, ensuring that innovative educational practices reach practitioners worldwide without financial barriers.

Among ACNS's prominent publications is the Diamond Open Access *Science Education Quarterly* (SEQ) that covers a broad range of topics aligned with the ICon-MaSTEd goals. Here are select articles from *Science Education Quarterly* categorized by conference topics:

- Biology Education
 - Utilization of instructional materials in supporting biology learning in Tanzania [7]
- Chemistry Education
 - Enhancing high school students' understanding of molecular geometry with augmented reality [8]

- The rebirth of home chemistry experiments: An international perspective and the Ukrainian context [9]
- A bibliometric analysis of learning environments in chemistry education [10]
- Programmed learning in chemistry education: a critical review of theory, application, and effectiveness [11]
- Physics Education
 - Broadening didactic resource of physics dictation [12]
 - A relativistic approach to teaching electrodynamics: Deriving Maxwell's equations from first principles [13]
 - A relativistic approach to teaching electrodynamics: Analysis of conductor interactions and relativistic foundations [14]
- Astronomy Education
 - From smartphones to stargazing: the impact of mobile-enhanced learning on astronomy education [15].
 - Enhancing student engagement and performance in high school astronomy through a differentiated homework approach [16]
- Earth Science Education
 - Teaching geography with GIS: a systematic review, 2010-2024 [17]
- Integrated Science Education
 - Implementing an integrated natural sciences course in Ukrainian high schools: A nationwide experiment from 2018-2022 [18]
 - Environmental factors influencing girls' participation in science education in Tanzanian secondary schools [19]
- Educational Technology
 - Elements of computer modelling: 12 studies for beginners. Study 1: Models and modelling [20]
 - Elements of computer modelling: 12 studies for beginners. Study 2: Main stages of modelling [21]

3.2. Institutional partners

The conference benefited from strong partnerships with three distinguished institutions. **Ben-Gurion University of the Negev, Israel**, where Professor Kiv served as a professor from 1998 to 2007, brought international perspective and expertise in advanced research methodologies. **Kryvyi Rih State Pedagogical University** served as the host institution, providing both physical and virtual infrastructure for the hybrid conference format. As one of Ukraine's leading pedagogical universities, KSPU brought decades of experience in teacher education and educational research. **Institute for Digitalisation of Education of the National Academy of Educational Sciences of Ukraine** contributed expertise in educational technology and digital transformation of learning environments. The Institute's involvement ensured that the conference addressed contemporary challenges in digital education, including issues of accessibility, quality assurance, and pedagogical innovation in online and blended learning contexts. Their research on educational digitalization in crisis conditions proved particularly relevant given the ongoing challenges faced by Ukrainian educators.

3.3. Organizational structure and support

The conference organizing committee, comprising representatives from all partner institutions, worked collaboratively to ensure the conference's success despite unprecedented challenges. The committee structure included:

- Program committee responsible for peer review processes, session organization, and maintaining academic standards. The committee reviewed 71 submissions and selected 31 high-quality papers through rigorous double-blind peer review.
- Technical support team managed the hybrid conference platform, ensuring seamless integration of in-person and virtual participation. This team's expertise proved crucial in maintaining conference continuity during air raid alerts and infrastructure disruptions.
- Publication committee oversaw the preparation and dissemination of conference proceedings, ensuring timely publication and broad accessibility of presented research.

ICon-MaSTEd 2025 program committee members:

- *Leon A. Abdillah*, Universitas Bina Darma, Indonesia [22]
- *George Abuselidze*, Batumi Shota Rustaveli State University, Georgia [23–25]
- *Svitlana Amelina*, National University of Life and Environmental Sciences of Ukraine, Georgia [26–28]
- *Spencer A. Benson*, Education Innovations International, LLC and University of Maryland, United States [29–31]
- *Liudmyla Bilousova*, Independent Researcher, Israel [32–34]
- *Olha Bondarenko*, Kryvyi Rih State Pedagogical University, Ukraine [35–39]
- *Oleksandr Burov*, Institute for Digitalisation of Education of the NAES of Ukraine, Ukraine [40–42]
- *Roman Danel*, VSTE in České Budějovice, Czech Republic [43–45]
- *Tetiana Derkach*, Kyiv National University of Technologies and Design, Ukraine [46–50]
- *Helena Fidlerova*, Slovak University of Technology in Bratislava, Slovakia [51]
- *Nataliia P. Franchuk*, Dragomanov State University of Ukraine, Ukraine [52–54]
- *Irina Georgescu*, Bucharest University of Economics, Romania [55–57]
- *Liudmyla Gryzun*, Simon Kuznets Kharkiv National University of Economics, Ukraine [58–61]
- *Oleksii Haluza*, National Technical University “Kharkiv Polytechnic Institute”, Ukraine [62–65]
- *Pavlo Hryhoruk*, Khmelnytskyi National University, Ukraine [66–68]
- *Andrii Iatsyshyn*, Center for Information-analytical and Technical Support of Nuclear Power Facilities Monitoring of the NAS of Ukraine, Ukraine [69–72]
- *Anna Iatsyshyn*, State Scientific Organization “Ukrainian Institute of Scientific Technical and Expertise and Information”, Ukraine [73, 74]
- *Dragos-Daniel Iordache*, National Institute for Research and Development in Informatics - ICI Bucuresti, Romania [75–78]
- *Michail Kalogiannakis*, University of Thessaly, Greece [79]
- *Arnold Kiv*, South Ukrainian National Pedagogical University named after K. D. Ushynsky, Ukraine & Ben-Gurion University of the Negev, Israel [80]
- *Taras Kobylnyk*, Drohobych Ivan Franko State Pedagogical University, Ukraine [81–83]
- *Oleksandr Kolgatin*, Simon Kuznets Kharkiv National University of Economics, Ukraine [84–86]
- *Elena Komarova*, NitrosData, LLC [87]
- *Tetiana Kramarenko*, Kryvyi Rih State Pedagogical University, Ukraine [88]

- *Milan Kubiato*, Jan Evangelista Purkyně University in Ústí nad Labem, Czechia [89–91]
- *Andrey I. Kupin*, Kryvyi Rih National University, Ukraine [92–95]
- *Olena Kuzminska*, National University of Life and Environmental Sciences of Ukraine, Ukraine [96–98]
- *Olena Lavrentieva*, Kryvyi Rih State Pedagogical University, Ukraine [99–101]
- *Olena Lokshyna*, Institute of Pedagogy of NAES of Ukraine, Ukraine [102]
- *Oksana Lytvyn*, Borys Grinchenko Kyiv Metropolitan University, Ukraine [103, 104]
- *Nataliia Maksyshko*, Zaporizhzhia National University, Ukraine [105]
- *Svitlana Malchenko*, Kryvyi Rih State Pedagogical University, Ukraine [106–111]
- *Mykhailo Medvediev*, ADA University, Azerbaijan [112–114]
- *Liliia Midak*, Vasyl Stefanyk Precarpathian National University, Ukraine [115–119]
- *Franco Milano*, University of Florence, Italy [120–123]
- *Iryna Mintii*, University of Łódź, Poland [124–129]
- *Mattia Monga*, University of Milan, Italy [130, 131]
- *Pavlo Nechypurenko*, Kryvyi Rih State Pedagogical University, Ukraine [132–136]
- *Yuliia Nosenko*, Institute for Digitalisation of Education of the NAES of Ukraine, Ukraine [137–139]
- *Laima Okunevičiūtė Neverauskienė*, Lietuvos Respublikos Vyriausybė, Lietuvos socialinių mokslų centras, Lithuania [140–142]
- *Vasyl Oleksiuk*, Ternopil Volodymyr Hnatiuk National Pedagogical University, Ukraine [143–145]
- *Kateryna Osadcha*, Norwegian University of Science and Technology, Norway [146–149]
- *Viacheslav Osadchyi*, Borys Grinchenko Kyiv Metropolitan University, Ukraine [150–152]
- *Jaderick Pabico*, University of the Philippines System, University of the Philippines Los Banos, Philippines [153]
- *Olha Pinchuk*, Institute for Digitalisation of Education of the NAES of Ukraine, Ukraine [154–157]
- *Oleg Pursky*, State University of Trade and Economics, Ukraine [158]
- *Natalya Rashevskaya*, Institute for Digitalisation of Education of the NAES of Ukraine, Ukraine [159–161]
- *Iryna Salnyk*, Volodymyr Vynnychenko Central Ukrainian State University, Ukraine [162–165]
- *Serhiy Semerikov*, Kryvyi Rih State Pedagogical University, Ukraine [166]
- *Etibar Seyidzade*, Baku Engineering University, Azerbaijan [167–170]
- *Yevhenii Shapovalov*, Junior Academy of Sciences of Ukraine, Ukraine [171–175]
- *Svitlana Shokaliuk*, Kryvyi Rih State Pedagogical University, Ukraine [176]
- *Andrii Striuk*, Kryvyi Rih National University, Ukraine [177]
- *Oksana Strutynska*, Dragomanov Ukrainian State University, Ukraine [178]
- *Myroslav Syvvi*, Ternopil Volodymyr Hnatiuk National Pedagogical University, Ukraine [179, 180]
- *Tetiana Tashtan*, Kryvyi Rih State Pedagogical University, Ukraine [181]
- *Viktorii Tkachuk*, Kryvyi Rih National University, Ukraine [182–184]
- *Maria Umryk*, Dragomanov Ukrainian State University, Ukraine [185–187]

- *Mayank Vahia*, TIFR Mumbai, India [188,189]
- *Tetiana Vakaliuk*, Zhytomyr Polytechnic State University, Ukraine [190–192]
- *Nataliia Valko*, Kherson State University, Ukraine [193–195]
- *Nataliia Veretennikova*, Lviv Polytechnic National University, Ukraine [196–198]
- *Kateryna Vlasenko*, National University of Kyiv-Mohyla Academy, Ukraine [199–201]
- *Yuliia Yechkalo*, Kryvyi Rih National University, Ukraine [202–204]

3.4. Commitment to open science and accessibility

All organizing partners share a commitment to open science principles, reflected in the conference's approach to knowledge dissemination. Conference proceedings are published under open access licenses, ensuring that research findings are freely available to educators worldwide, regardless of institutional resources. Video recordings of all sessions are made available on the "Not So Easy Science" YouTube channel (<https://www.youtube.com/@NotSoEasyScience>), extending the conference's reach beyond registered participants.

This commitment to accessibility is particularly important given the conference's focus on education in crisis conditions. By removing financial and technical barriers to accessing conference content, the organizers ensure that innovative educational solutions developed in response to challenging circumstances can benefit educators facing similar challenges globally.

The collaborative organizational structure of ICon-MaSTEd 2025 demonstrates that international scientific cooperation can thrive even in the most challenging circumstances. The dedication of organizers, partners, and participants in maintaining this platform for educational innovation honors Professor Kiv's vision of science and education as universal human endeavors that transcend political boundaries and unite us in our common pursuit of knowledge and betterment of society.

4. Proceedings overview

4.1. Mathematics Education

The Mathematics Education section of ICon-MaSTEd 2025 featured eight innovative papers that explored contemporary challenges and opportunities in mathematics pedagogy, ranging from teacher preparation methodologies to century-long institutional perspectives. This session, moderated by Iryna Mintii and Svitlana Malchenko, brought together researchers from multiple Ukrainian universities and international institutions to share their insights on advancing mathematical education in the 21st century.

The session opened with a presentation by Achkan et al. [205] on "Using the case method while training would-be Mathematics teachers". The authors developed a comprehensive methodology for implementing the case method in mathematics teacher preparation programs, proposing a classification system for cases based on execution time, presentation method, complexity level, and problem breadth. Their experimental verification confirmed the practicality of using the case method, with statistical analysis showing significantly higher achievement levels in methodological disciplines among students in the experimental group compared to the control group. The methodology encompasses six key components: motivation of educational activity, goal setting, content, methods, forms, and means of learning, providing a structured approach to modeling real professional activities that mathematics teachers encounter in their practice.

Following this pedagogical innovation, Vlasenko et al. [206] presented their research on the "Application of the Cobb-Douglas function for the formation of would-be economists' analytical skills". This interdisciplinary approach demonstrates how mathematical modeling, specifically through the Cobb-Douglas production function, can develop crucial analytical skills in economics students. The authors systematized problems using a combination of table and clustering methods, organizing them into three types that progressively build students' abilities

in computing partial derivatives, constructing logical arguments, and adapting mathematical results to economic contexts. During the discussion, Professor Vladimir Sokolov raised an insightful question about the potential for revisiting the Cobb-Douglas function across multiple mathematical topics to deepen understanding, highlighting the challenge of limited instructional time while emphasizing the function's versatility in demonstrating real-world applications of bivariate functions, derivatives, and optimization problems.

Lovianova et al. [207] contributed a comprehensive study on "Measurement key competencies of high school students in teaching of Natural Science and Mathematics subjects", addressing the critical need for competency-based assessment in modern education. Their research developed instruments for measuring key competencies that align with contemporary educational standards, providing valuable insights into how mathematics education can contribute to broader educational goals beyond subject-specific knowledge.

The international perspective was enriched by Voievoda et al. [208] with their comparative study on "Peculiarities of implementing digital games in mathematics lessons in secondary schools of Ukraine and Israel". This cross-national research examined how gamification strategies can enhance mathematical learning, revealing both universal principles and culturally specific considerations in implementing educational technology across different educational systems.

Addressing motivational challenges in higher education, Petrovych et al. [209] presented "Modern aspects of forming the motivation of learning activities of bachelors of mathematics in the process of studying professional disciplines". Their research identified key factors influencing student motivation and proposed strategies for maintaining engagement throughout the demanding mathematics curriculum, particularly important given the abstract nature of many advanced mathematical concepts.

The increasing importance of adaptive learning technologies was highlighted by Astafieva et al. [210] in their paper "Supporting the mathematical education of STEM students: development of an adaptive learning course for independent study". The authors described the development of an adaptive learning platform that responds to individual student needs, supporting self-directed learning and addressing the diverse preparation levels of STEM students. The discussion revealed plans for an ambitious international Erasmus project involving eight universities across Ukraine, Slovakia, Czech Republic, and Norway to further develop and implement adaptive learning approaches.

A particularly significant historical perspective was provided by Kramarenko and Semerikov [211] in "A century of mathematics education at Kryvyi Rih State Pedagogical University: Honoring the past, shaping the future". This comprehensive historical analysis traced the evolution of mathematics education at the institution from its founding through Soviet times to contemporary challenges. Using qualitative case study methodology with multiple data sources including archival documents and 15 oral history interviews, the research illuminated patterns of continuity and change across different political and educational paradigms. The presentation sparked thoughtful discussion about the enduring values of fundamental mathematical knowledge and logical reasoning that transcend political systems, while acknowledging the need for adaptation to contemporary educational demands.

The session concluded with Klochko et al. [212] presenting "Mathematics for digital signal processing: series and integrals of Fourier in professional training", which addressed the critical intersection of pure mathematics and engineering applications. The authors emphasized how Fourier analysis serves as a fundamental bridge between abstract mathematical concepts and practical engineering problems, particularly relevant in the digital age. Their approach to integrating constructive and mathematical thinking through visualization and animation techniques demonstrated how modern pedagogical tools can make complex mathematical concepts more accessible to engineering students, addressing the common challenge of "math anxiety" among technical students.

Throughout the session, several cross-cutting themes emerged. First, the integration of technology and digital tools was prominent across multiple presentations, from adaptive learning platforms to visualization techniques for complex mathematical concepts. Second, the importance of contextualizing mathematical learning through real-world applications was consistently emphasized, whether through economic modeling, engineering applications, or gamification. Third, the session highlighted the ongoing challenge of maintaining mathematical rigor while making content accessible and engaging for diverse student populations.

The discussion periods revealed rich exchanges between participants, with particular attention to the balance between theoretical foundations and practical applications. As noted in the closing remarks by session moderators, while artificial intelligence and machine learning were not central topics in this session, participants acknowledged the potential of these technologies to enhance mathematical productivity, referencing Terence Tao's recent explorations of AI-assisted theorem proving as an indicator of future directions in mathematical education.

The Mathematics Education section thus demonstrated the field's dynamic response to contemporary challenges while maintaining its commitment to fundamental mathematical principles. The research presented offers valuable insights for educators seeking to prepare students for an increasingly complex and technologically sophisticated world while preserving the essential character of mathematical thinking that has defined the discipline for centuries. The session's conclusion emphasized the importance of annual conferences like ICon-MaSTEd in maintaining international collaboration and knowledge exchange, particularly crucial given the current geopolitical challenges facing the region.

4.2. Physics Education

The Physics Education section of ICon-MaSTEd 2025 featured five innovative papers that explored diverse approaches to physics teaching, from early childhood interventions to advanced computational methods. This session, held on May 14, demonstrated the breadth of physics education research, addressing challenges from fundamental skill development to sophisticated teacher training programs. The presentations highlighted both practical tools for classroom implementation and theoretical frameworks for understanding physics learning across different age groups and educational contexts.

The session opened with Broniola et al. [213] from the Philippines presenting "Conversion Factor Wheel: a tool to improve unit conversion skills in Grade 12 STEM students". This practical research addressed a fundamental challenge in physics education – unit conversion competency. The team developed an Android-based application specifically designed for students at Cantilan National High School, providing a visual and interactive approach to converting units of length, mass, volume, and time. Using an experimental design with pre- and post-test assessments, the study demonstrated remarkable improvement in student performance, with mean scores increasing from 4.8 (48%) to 9.45 (94.5%), a significant mean difference of 4.65. The psychological validity rating of 74.13% indicated high student satisfaction and acceptance. Crucially, the app's offline functionality addressed infrastructure challenges, as the presenters noted: "This app is highly valuable for CNHS students because it can be used remotely without an internet connection, giving it a significant advantage over other online-only tools". This feature proved particularly important for ensuring educational continuity in areas with limited internet access.

A particularly innovative approach to early childhood physics education was presented by Ioannou et al. [214] with their paper "Fostering early understanding of vaporization in 5-6-year-olds via engineering design". This qualitative study involved 19 preschool children and employed a sophisticated Engineering Design Process (EDP) framework with four distinct stages: Problem, Inquiry, Designing and Testing, and Conclusions and Presentation. The researchers used everyday scenarios, such as wet clothes drying and water disappearing from a glass, to

make abstract concepts tangible for young learners. During the discussion, questions arose about adapting complex physics concepts for such young children. As the presenter explained, “We do not try to give children the total scientific accessible idea, but something less” – referring to their concept of “precursor models” that serve as cognitive bridges between children’s intuitive understanding and formal scientific knowledge. The study demonstrated that children could successfully connect thermal exchanges with vaporization phenomena, with post-test results showing improvement from 10% to 79% in understanding key concepts. When asked about potential adaptations to other media formats, the researchers acknowledged interest in developing animated content to further enhance accessibility.

Abdulayeva [215] from Kazakhstan contributed “Information educational environment and scientific process skills: experimental evaluation using the Likert scale”. This three-year longitudinal study (2021-2023) involved 56 middle school students divided into experimental and control groups. The experimental group engaged with ICT-enhanced laboratory activities following a structured progression model: adaptation (7th grade), development (8th grade), and self-realization (9th grade). Using a 31-question Likert scale questionnaire assessing nine core scientific process domains, the study demonstrated significant improvements in students’ self-perceived scientific competencies. During the Q&A, participants inquired about specific physics experiments that worked best with ICT integration. The presenter noted that mechanics experiments were particularly effective, as “in Excel we lost analysis data mechanical experiments”, highlighting the practical applications of spreadsheet software in physics education. The discussion also addressed the challenge of balancing traditional hands-on laboratory work with digital tools, emphasizing that ICT should enhance rather than replace physical experimentation.

Sadovyi et al. [216] presented a sophisticated theoretical and computational approach with “Computer modelling of atomic-molecular states leading to Maxwell distribution”. This research developed an integrative method using Python’s Matplotlib module to create visual-dynamic computer models of gas molecular velocity distributions. The team created simulations for four gases (helium, nitrogen, oxygen, and carbon dioxide) at 300K temperature across velocity ranges from 0 to 1400 m/s with 10 m/s increments. The pedagogical experiment at Volodymyr Vynnychenko Central Ukrainian State University and Dnipro State Medical University showed improved student comprehension of abstract thermodynamic concepts through visualization. The presenters emphasized how their approach “develops students’ computational thinking, fosters worldviews oriented toward independent truth-seeking, and provides opportunities to implement research ideas directly during studies”. The visual representation of Maxwell distribution helped students understand the physical meaning of temperature, pressure, and energy concepts that are typically challenging to grasp through traditional teaching methods.

The session concluded with Pavlenko et al. [217] presenting “Experience in the development and implementation of the course ‘Python for Physics Teachers’”. This comprehensive professional development program consisted of 13 lectures and 12 practical sessions designed to equip physics teachers with computational skills. The course covered foundational Python programming, visualization of physical phenomena, and modeling of school physics topics. During the discussion, concerns about the impact of large language models like ChatGPT on student learning arose. The presenter acknowledged this challenge, noting difficulties in distinguishing between student-generated and AI-generated code. A thoughtful exchange followed about embracing rather than resisting AI tools, with one participant suggesting: “Probably it will be more productive... our students should use this model and explain, modify and produce a new model”. The discussion highlighted the need for physics education to adapt to AI-enhanced learning environments while maintaining focus on conceptual understanding and critical thinking skills.

Throughout the session, several unifying themes emerged. First, the importance of

visualization and interactivity in making abstract physics concepts accessible to learners of all ages. Second, the critical role of appropriate technological integration that enhances rather than replaces traditional physics teaching methods. Third, the need for teacher professional development to effectively implement new tools and approaches. Fourth, the challenge of maintaining educational quality while adapting to technological disruptions like AI and remote learning requirements.

The session concluded with warm exchanges between participants, with the moderator noting it was “the best session as for today”, emphasizing the collaborative spirit and shared commitment to advancing physics education despite challenging circumstances. The research presented demonstrated that physics education continues to evolve, incorporating new technologies and pedagogical approaches while maintaining its fundamental goal of developing scientific understanding and reasoning skills.

4.3. Astronomy Education

The Astronomy Education section featured a single but comprehensive paper that addressed fundamental challenges in teaching astronomical concepts within contemporary educational contexts. This focused presentation demonstrated how astronomy education serves as a unique interdisciplinary platform for developing both scientific competencies and broader educational goals.

Malchenko [218] presented “Implementation of a competency-based approach in teaching astrophysics and astronomy”, offering a thorough examination of how astronomy education can transcend traditional knowledge transmission to develop essential 21st-century competencies. The research employed qualitative methodology, including content analysis of curricula, expert review of lesson plans, and systematic comparison with international best practices. The presenter emphasized that “astronomy is very interesting but not very popular... among the teachers of physics”, highlighting a fundamental challenge in the field. Despite this, Malchenko argued convincingly that astronomy provides unique opportunities for competency development that other subjects cannot easily replicate.

The presentation detailed how astronomy naturally integrates multiple disciplines – physics, mathematics, chemistry, and even philosophy – making it an ideal vehicle for holistic education. The competency-based approach shifts focus from memorizing celestial facts to developing practical skills: data analysis, problem-solving, scientific reasoning, and technological literacy. The research identified core principles including result-oriented learning, integration of knowledge and skills, practical application, flexibility, and continuous self-assessment. As Malchenko noted, “Today’s world demands more than just theoretical knowledge. Students need to be able to adapt, solve problems, and work effectively in teams”.

During the extensive discussion period, practical implementation challenges dominated the conversation. When asked about organizing real telescope observations, Malchenko acknowledged significant logistical hurdles: “It’s very hard to organize real observing with telescope... I need good weather. I need some many interesting bodies on the night sky”. The presenter described requiring specific lunar phases for optimal first-time observations, explaining that “when moon in the first phases... you have a very interesting emotion”, highlighting the importance of carefully orchestrated observational experiences to maintain student engagement.

A particularly fascinating aspect of the discussion centered on the use of professional astronomical data in education. Malchenko detailed how students work with real data from solar observations and variable star catalogs, utilizing resources like SIMBAD and other professional databases. The presenter shared a remarkable success story: “One of pupils three years ago... discovered a new type of stars. She was in the ninth class... she used computer science specific computer apps”. This example powerfully illustrated how authentic scientific research can be integrated into secondary education, providing students with genuine discovery opportunities

while developing both astronomical knowledge and computational skills.

The conversation took a poignant turn when discussing resources and facilities. Malchenko mentioned the loss of access to the Crimean Astronomical Laboratory, stating, “Unfortunately we can’t use this laboratory today and more than 10 years”, a reminder of how geopolitical circumstances impact scientific education. Despite such challenges, the presenter emphasized adaptation through virtual observations, online databases, and collaborative international projects that provide alternative pathways for astronomical education.

The research presented practical examples of competency development through astronomy. Students learn to work with large datasets, apply mathematical models to real phenomena, use modern software for data analysis, and communicate scientific findings effectively. The interdisciplinary nature of astronomy projects – combining observation, computation, theoretical understanding, and presentation skills – creates rich learning environments that prepare students for diverse career paths, not just in astronomy but in any field requiring analytical and problem-solving capabilities.

Malchenko’s presentation also addressed assessment challenges in competency-based astronomy education. Traditional testing methods often fail to capture the full range of skills developed through astronomical study. The research proposed portfolio-based assessment, project presentations, and peer evaluation as more appropriate evaluation methods that align with competency development goals. These approaches allow students to demonstrate not just knowledge retention but also their ability to apply astronomical concepts in novel situations, work collaboratively on complex problems, and communicate scientific ideas effectively.

The session revealed astronomy education’s unique position in the curriculum as a gateway science that can inspire lifelong learning and scientific literacy. Despite challenges including limited class time, lack of specialized teacher training, and equipment constraints, the research demonstrated that well-designed competency-based approaches can transform astronomy from a marginal subject into a powerful educational tool. The emphasis on using freely available online resources, citizen science projects, and virtual observatory tools showed how modern astronomy education can be accessible even in resource-constrained environments.

The discussion concluded with reflections on future directions for astronomy education. Participants expressed hope that despite current challenges, the collaborative spirit of the international astronomy education community would continue to foster innovation and resource sharing. The session highlighted how astronomy, perhaps more than any other science, connects students to fundamental questions about our place in the universe while developing practical skills essential for the modern world. As Malchenko concluded, looking toward future programs that would allow students to pursue “real scientific awards” through astronomical research, the presentation demonstrated that astronomy education, when properly implemented, serves not just as a subject to be learned but as a platform for developing the critical thinking, technological competency, and scientific literacy essential for the 21st century.

4.4. Chemistry Education

The Chemistry Education section of ICon-MaSTEd 2025 featured two papers that addressed critical challenges in chemistry pedagogy, from teaching in foreign language environments to implementing reflective practices in organic chemistry instruction. This session, held on May 15, demonstrated innovative approaches to overcoming cognitive load challenges and enhancing student engagement through systematic reflection, highlighting the adaptability of chemistry education in diverse and challenging contexts.

The session opened with Derkach and Yaroshenko [219] presenting “Instructional design for teaching analytical chemistry in English as a foreign language”. This comprehensive study addressed the unique challenges of teaching complex chemical concepts to Chinese undergraduate students at Kyiv College of the Qilu University of Technology. The research, spanning 2019-

2023 and involving approximately 800 students across biotechnology and chemical technology programs, revealed a paradoxical trend: while students' English proficiency steadily improved over the years (from 60-62 points in 2019 to 74-76 points in 2023), their analytical chemistry exam results remained static at 75-77 points despite unchanged curricula and teaching staff. The authors systematically optimized instructional materials based on cognitive load theory, implementing changes across multiple dimensions. They reduced the total number of slides by 16% while increasing the average number of integrated elements per slide, transitioning from isolated information presentation to more cohesive, contextually linked content. As the presenter explained during the Q&A, cognitive load was measured using the secondary task method, where students performed dual tasks requiring the same cognitive resources, with reaction times indicating load levels. The optimization included three key strategies: managing intrinsic load through graduated complexity and the "part-whole" approach, reducing extraneous load by preventing split-attention effects and adhering to multimedia principles, and increasing germane load through worked examples and conceptual diagrams. Particularly innovative was their application of Johnstone's triangle, integrating macro, micro, and symbolic levels of chemical knowledge representation. The number of slides showing isolated levels decreased while those demonstrating double and triple transitions increased, with triple transitions growing from nearly zero to 10% of content.

Following this methodological innovation, Kutuhina, Kravchenko, and Nechypurenko [220] presented "Organisation of students' reflective activity when studying the topic 'Oxygen-containing organic compounds'". Their research, presented through a pre-recorded video due to technical constraints, addressed the critical gap between theoretical knowledge and practical application in organic chemistry education. A survey of 28 chemistry teachers in Kryvyi Rih revealed that while 89.3% considered reflection necessary for creating a developmental learning environment, only 50% systematically organized reflective activities, and merely 14.28% applied these methods when teaching oxygen-containing organic compounds. The authors developed a five-stage model of reflective activity: transpositional (role position change), reproductive (sequence reconstruction), analytical-evaluative (multifaceted analysis), resultative (fixation of outcomes), and prognostic (future planning). Their practical implementations included innovative techniques such as the "Microphone" method for content reflection, "YES or NO?" games for conceptual understanding, "Snowball" exercises for collaborative reflection, and "Fishbone" diagrams for process analysis. During the discussion, provocative questions arose about the dual nature of reflection involving both students and teachers. As translated during the session, the teacher "as the organizer of learning should understand why they are doing anything at the lesson", emphasizing that reflection serves as bidirectional feedback enabling continuous instructional improvement. When asked about extending reflection to homework and independent study, the presenters acknowledged this as an important area for future research, noting they had focused primarily on classroom activities but recognized the potential for broader application.

The Chemistry Education session revealed several critical insights for the field. First, the challenge of teaching chemistry in foreign language contexts extends beyond simple translation issues to fundamental cognitive processing differences. The counterintuitive finding that improved language skills did not correlate with better chemistry performance suggests that discipline-specific cognitive demands require targeted instructional design rather than general language support. Second, the widespread recognition but limited implementation of reflective practices indicates a significant theory-practice gap in chemistry education. Teachers acknowledge the value of reflection but lack practical tools and training for systematic implementation.

The COVID-19 pandemic's impact featured prominently in both presentations. Derkach and Yaroshenko noted that their instructional optimizations were partly driven by the need to adapt

to remote learning during 2020-2021, with students in China and teachers in Ukraine. The pandemic revealed existing weaknesses in instructional design while accelerating innovation. As one presenter noted regarding the shift from traditional to online learning, “the combination of high intrinsic and extraneous cognitive load can become critical for learning, as it can significantly exceed the capabilities of working memory”, emphasizing the heightened importance of cognitive load management in remote contexts.

Both presentations emphasized the importance of visualization and multi-level representation in chemistry education. Derkach and Yaroshenko’s use of Johnstone’s triangle to integrate macroscopic, microscopic, and symbolic levels mirrors Kutuhina et al.’s emphasis on connecting abstract concepts to observable phenomena through techniques like the Fishbone diagram. This convergence suggests that effective chemistry education requires systematic approaches to helping students navigate between different representational levels, particularly important given chemistry’s inherent abstraction.

The discussion periods revealed practical implementation challenges. Teachers face time constraints, with one noting the difficulty of covering extensive curricula while implementing reflective activities. Resource limitations, particularly in conflict-affected regions, necessitate creative solutions. The loss of access to physical laboratories during the pandemic and ongoing conflict has accelerated the adoption of virtual laboratories and simulation tools, though presenters emphasized these complement rather than replace hands-on experimentation.

Cultural considerations emerged as significant factors. Teaching Chinese students required adaptations beyond language, accounting for different learning preferences and educational backgrounds. Similarly, implementing Western pedagogical approaches like systematic reflection in Ukrainian classrooms required cultural adaptation. As noted during discussions, Chinese students demonstrated “more global” learning styles compared to Ukrainian students, though pandemic-driven remote learning appeared to be shifting Ukrainian students toward similar patterns.

The session highlighted the evolution of chemistry education assessment. Traditional testing methods inadequately capture the complex competencies developed through modern chemistry instruction. Both presentations advocated for alternative assessment approaches: Derkach and Yaroshenko through integrated problem-solving tasks that span representational levels, and Kutuhina et al. through portfolio-based assessment and peer evaluation that capture reflective competencies. These approaches align with broader educational trends toward competency-based rather than knowledge-based evaluation.

Looking forward, both presentations pointed toward increased technology integration while maintaining pedagogical focus. The forced experimentation during the pandemic has yielded valuable insights about effective online chemistry instruction that will persist post-crisis. However, presenters emphasized that technology serves pedagogical goals rather than driving them. As Derkach noted, the goal is not to “avoid presenting data in several autonomous formats simultaneously” through technology but to use it purposefully to reduce cognitive load and enhance understanding.

The Chemistry Education section thus demonstrated the field’s resilience and adaptability in facing multiple simultaneous challenges: linguistic barriers, cognitive load management, pandemic disruption, and the need for pedagogical innovation. The research presented offers practical strategies for educators worldwide facing similar challenges, from systematic instructional design based on cognitive science principles to implementing reflective practices that deepen conceptual understanding. The session’s conclusion emphasized that these innovations, born from necessity, represent genuine advances in chemistry pedagogy that will benefit students long after current crises pass. The warm exchanges between presenters and participants, despite technical challenges and language barriers, underscored the international chemistry education community’s commitment to collaborative problem-solving and continuous improvement.

4.5. *Earth Science Education*

The Earth Science Education section of ICon-MaSTEd 2025 featured two comprehensive papers on geospatial analysis and data integration in geography education, demonstrating how modern geographic information technologies can transform traditional geography teaching. This session, held on May 15, brought together researchers from Ukrainian institutions to explore the theoretical foundations and practical implementations of geospatial technologies in school geography courses, addressing both opportunities and challenges in bringing real-world geographic analysis into classrooms.

The session began with Kholoshyn et al. [221] presenting “Principles and methods of integrating geospatial analysis into the school geography course”. The authors argued that geographic information technologies have become essential tools for understanding geographic space, enabling students to study spatial differentiation of processes, objects, and phenomena while solving practical problems across ecology, agriculture, transport, and urban planning. Their research identified six fundamental principles for implementing geospatial analysis in schools. First, geospatial technologies should be integrated into existing curriculum topics rather than added as supplementary content, making traditional material more accessible through new perspectives. Second, working with real geospatial data makes learning interactive and practically oriented, with students able to collect data through field research, GPS devices, and community surveys. Third, project activities provide effective means for applying knowledge to real-world problems, as exemplified by students at Bishop Dunne Catholic School in Dallas who analyzed police robbery data, identified hotspot areas, and provided recommendations that contributed to actual crime reduction. Fourth, Geographic Information Systems (GIS) serve as powerful support tools, though the authors noted teachers should begin with accessible online platforms like MapMaker Interactive and GeoInquiries before progressing to complex software like ArcGIS or QGIS. Fifth, interdisciplinary integration allows geospatial analysis to enhance not only geography but also history, biology, economics, and mathematics instruction. Sixth, successful implementation requires comprehensive teacher training in geoinformation technologies.

Building on these principles, Kholoshyn et al. [222] presented “Geospatial data in school geography courses: Sources, methodological features of use and implementation challenges”. This complementary research examined the practical aspects of implementing geospatial data in education, emphasizing that geospatial data represents more than coordinates – it forms the “dynamic basis of our interconnected world” combining spatial, attribute, and temporal components. The authors established six essential criteria for educational geospatial data: high quality and currency, accessibility without financial barriers, clarity with appropriate structure, alignment with educational objectives, support for interactive exploration, and protection of privacy and security. They detailed various pedagogical approaches including problem-based learning where students analyze real environmental challenges, project activities involving authentic data collection and analysis, gaming technologies like GeoGuess that develop spatial reasoning through interactive challenges, and independent work with professional databases and satellite imagery. The presentation featured practical examples, such as students using Sentinel-5P satellite data to analyze NO₂ pollution patterns across Ukrainian cities, demonstrating how authentic scientific data can be integrated into secondary education.

During the extensive Q&A session, critical implementation questions emerged. When asked about the optimal phase for introducing geospatial analysis, the presenters emphasized adaptability across all educational stages while considering individual student characteristics. They recommended beginning with demonstration and visualization for younger students, progressively introducing analytical tools, and culminating in full project-based implementations for senior students. This graduated approach acknowledges both cognitive development and technical skill progression. Tetiana Derkach inquired about specific project examples, prompting detailed descriptions of successful implementations. One highlighted project involved combining

tectonic plate maps with earthquake data to help students discover correlations between seismic activity and plate boundaries – a powerful demonstration of how geospatial analysis makes abstract geological concepts tangible. Another example described monitoring Carpathian forest development over time, illustrating environmental change and human impact. The presenters emphasized how such projects develop cause-and-effect thinking while integrating multiple disciplines.

Technical accessibility emerged as a crucial concern. When asked about specialized software requirements, the presenters stressed the availability of free, browser-based tools requiring no special installation. They highlighted platforms like Google Maps, OpenStreetMap, and educational-specific resources like GeoInquiries that provide professional-grade analysis capabilities without cost barriers. This emphasis on accessibility reflects awareness of resource constraints in many schools, particularly relevant given Ukraine's current challenges. The discussion about data quality and verification prompted insights about crowdsourced platforms like OpenStreetMap, where "different researchers can take and correct the data", creating collaborative knowledge construction opportunities while teaching critical evaluation skills.

The integration of artificial intelligence in geospatial analysis generated thoughtful discussion. When asked about student use of AI tools, presenters acknowledged both opportunities and challenges. They noted AI's tendency to "make mistakes", especially with Ukrainian-language queries, emphasizing the need for verification skills. Rather than viewing AI as a threat, they positioned it as another tool requiring critical evaluation – students and teachers must "learn with artificial intelligence how to use it in our studies". This perspective frames AI literacy as an essential component of modern geographic education.

Practical challenges dominated much of the discussion. Limited instructional hours in geography curricula remain a primary obstacle, with most schools allocating only 2-3 weekly hours to geography. The presenters suggested integrating short 15-20 minute geospatial tasks into existing topics rather than requiring curriculum expansion. They provided specific examples, such as using Map Viewer to create demographic visualizations when studying population geography, demonstrating how geospatial analysis enhances rather than replaces traditional content. The lack of adapted educational materials and teacher training represents another significant barrier. While professional geospatial data sources proliferate, most lack pedagogical adaptation for secondary students. The presenters advocated for developing simplified, theme-oriented datasets with clear educational alignments, alongside comprehensive teacher professional development programs.

Methodological considerations received detailed attention when asked about the most effective approaches for geography lessons. While acknowledging this area needs further research, the presenters identified several promising methods: working with mapping services for visualization and basic analysis, thematic mapping for pattern recognition and correlation, and spatial modeling for understanding geographic processes. They emphasized that method selection depends on learning objectives, student capabilities, and available resources. The discussion revealed tension between the potential of advanced technologies and practical classroom realities, with presenters advocating for pragmatic approaches that prioritize pedagogical effectiveness over technological sophistication.

Both presentations addressed the unique challenges facing Ukrainian education during wartime. References to lost access to facilities, such as the Crimean Astronomical Laboratory mentioned in another session, and the need for offline-capable resources reflect the reality of education under conflict. However, rather than dwelling on limitations, the presenters demonstrated remarkable adaptability, showing how virtual resources and international collaboration can partially compensate for physical resource loss. The emphasis on freely available online tools and crowdsourced data takes on additional significance in this context, providing continuity despite infrastructure disruptions.

Looking toward future developments, the presenters introduced the concept of GeoAI (Geospatial Artificial Intelligence), combining AI, GIS, and geospatial data to address complex geographic problems. While acknowledging GeoAI remains nascent in educational contexts, they outlined potential applications including automated data collection from satellite imagery, real-time processing of geographic information, and predictive spatial analytics for environmental and urban planning. These capabilities could revolutionize geography education by providing students with tools for authentic scientific investigation previously available only to professional researchers.

The session revealed geography education at a transformation point, where traditional map-based instruction evolves into dynamic, data-driven exploration of spatial phenomena. The research presented demonstrates that despite significant challenges – limited resources, insufficient training, curriculum constraints, and ongoing conflict – innovative educators are successfully integrating geospatial technologies to enhance geographic understanding. The emphasis on practical, accessible solutions rather than idealized implementations provides valuable guidance for educators worldwide facing similar constraints.

The Earth Science Education section thus offered both vision and pragmatism, showing how geospatial analysis can transform geography from a descriptive to an analytical discipline while acknowledging the real challenges of implementation. The presenters' combination of theoretical frameworks, practical examples, and honest discussion of obstacles provides a roadmap for educators seeking to modernize geography instruction. As noted in closing remarks, these technologies offer students not just knowledge about the world but tools to analyze, understand, and ultimately shape it – a capability increasingly essential in our interconnected, spatially complex global society. The session concluded with expressions of gratitude for the opportunity to share experiences and learn from international colleagues, reinforcing the importance of continued collaboration in advancing geographic education despite challenging circumstances.

4.6. Computer Science Education

The Computer Science Education section of ICon-MaSTEd 2025 featured seven innovative papers that addressed contemporary challenges in computing education, from artificial intelligence integration to game development pedagogy. This session, held on May 16, 2025, brought together researchers and educators from Ukraine and international institutions to explore how computer science education can evolve to meet the demands of a rapidly changing technological landscape while maintaining pedagogical effectiveness and student engagement.

The session opened with a compelling presentation by Osadcha et al. [223] on “AI tools and their application for developing soft skills of computer science students: the perspectives of IT specialists and university teachers”. This timely research addressed the critical intersection of technical and interpersonal competencies in IT education. Through comprehensive surveys of IT professionals and educators, the authors identified a strong correlation between teaching experience and satisfaction with AI tools for developing soft skills. Their findings revealed that tools such as ChatGPT, Grammarly, Microsoft Copilot, and various intelligent tutoring systems can effectively support the development of communication, collaboration, critical thinking, and problem-solving abilities. The presentation sparked discussion about implementation strategies, with particular attention to helping less experienced educators become comfortable with AI integration. As one participant noted during the Q&A, the research found that “the more teaching experience respondents have, the more their satisfaction with AI exploiting”, highlighting the need for targeted professional development programs.

Building on the theme of cognitive development through technology, Chernenko and Lysenko [224] presented “The impact of AI on the development of cognitive competence in gifted youth”. Their study, conducted at the “Polit” Science Lyceum, demonstrated how participation in AI project development significantly enhanced students' scientific thinking, critical analysis, and

decision-making skills. The research emphasized that cognitive competence has become essential for young people to adapt to new conditions of work and life, particularly in the context of rapid technological change. The authors argued that engaging gifted students in AI projects not only develops their technical skills but also cultivates the flexible thinking necessary for addressing global challenges through innovative approaches and cutting-edge technologies.

Koniukhov et al. [225] contributed an important methodological framework with their paper on “Creating of collaborative learning framework for Computer Science students training in the field of database design”. The authors conducted a comprehensive bibliometric analysis using Scopus data to identify key trends in collaborative learning and database education. Their framework emphasized techniques such as the Jigsaw method and gather.town platform for online collaboration, demonstrating how collaborative learning can develop both hard skills in database design and essential soft skills through group interaction. The research particularly highlighted the challenges of organizing collaborative learning in online environments, including increased teacher workload for live group management and technical problem-solving, while also showcasing successful implementations in courses like “Software Product Line Engineering”.

A particularly innovative mathematical perspective was provided by Gryzun [226] with “Computational and algorithmic explorations of polygonal numbers: their role in computer science education”. This research addressed the challenge of students’ insufficient awareness of the value of mathematical knowledge for their professional development as computer scientists. By using polygonal numbers as a bridge between abstract mathematics and practical computation, the author demonstrated how these mathematical concepts appear in real-world applications from spider webs to network topology. The exploration activity developed by Gryzun integrates algebra, geometry, and computation, providing students with hands-on experience in mathematical modeling and algorithm development. The paper’s emphasis on making mathematics tangible and relevant resonated with educators seeking to overcome the common perception among CS students that advanced mathematics is purely abstract and disconnected from professional practice.

The growing importance of game development in computer science education was highlighted by Pruhlo and Moiseienko [227] in their presentation on “Integrating game development into the secondary school informatics curriculum: A case study from Ukraine”. Their implementation of a Unity-based game development course demonstrated significant improvements in student engagement and programming skills. Students reported that creating interactive games made abstract programming concepts concrete and meaningful, with one participant noting, “The best part of the class was seeing my own ideas come to life on the screen”. The authors identified both challenges, such as varying levels of prior programming experience and technical limitations of school computer labs, and success factors, including the intrinsically motivating nature of game creation and the balance between structured learning and creative freedom.

Complementing this focus on game-based learning, Pozniakov and Merzlykin [228] presented “Development of a PyGame workshop for extracurricular Computer Science education”. Their analysis of existing Ukrainian extracurricular programs revealed significant gaps, including outdated materials, expensive software requirements, and inappropriate inclusion of Russian-language resources. The authors developed a comprehensive PyGame workshop using Google Sites, providing free, accessible learning materials with step-by-step game creation guides. The workshop’s project-based learning approach, where students build a functional game that serves as a foundation for future projects, received positive feedback from participants who appreciated the practical orientation and clear progression of skills. As the authors noted, Python and PyGame were chosen for their accessibility, extensive documentation, and suitability for beginners, making game development approachable for students with basic programming knowledge.

The session concluded with Ryzhanina and Tarasova [229] presenting “Development of an

elective course on Scratch programming for specialized computer science education in lyceums". Their 12-week pedagogical experiment demonstrated significant improvements in students' Scratch programming skills and computational thinking abilities. The research showed that 90% of participating students had prior exposure to Scratch in school, but the specialized elective course deepened their understanding and creative application of programming concepts. Students' self-assessed proficiency increased from an average of 6.3 to 8.6 points out of 10, with project evaluations averaging 5.1 out of 6 possible points. Student feedback highlighted the course's effectiveness, with one participant commenting, "Interesting tasks, clearly described. Could use separate lessons on algorithms and events", while another praised the extensive effort visible in the course design.

Throughout the session, several unifying themes emerged that characterize the current state and future directions of computer science education. First, the integration of artificial intelligence is no longer optional but essential, both as a subject of study and as a pedagogical tool. Second, the development of soft skills alongside technical competencies has become a central concern, reflecting industry demands for well-rounded professionals. Third, game development and visual programming environments like Scratch and PyGame serve as powerful motivational tools that make abstract concepts tangible and engaging. Fourth, collaborative learning frameworks are essential for developing both technical and interpersonal skills, though they require careful adaptation for online and hybrid environments.

The session also highlighted specific challenges facing computer science education, particularly in the Ukrainian context. These include resource limitations in schools, the need to update curricula to remove outdated or inappropriate content, and the challenge of supporting educators with varying levels of experience with new technologies. However, the research presented also demonstrated remarkable resilience and innovation, with educators developing creative solutions such as free online workshops, adaptive learning platforms, and project-based curricula that engage students despite challenging circumstances.

The discussion periods revealed rich exchanges between participants about practical implementation strategies. Questions about adapting methodologies for different cultural settings and resource constraints led to thoughtful discussions about the universality of certain pedagogical approaches versus the need for localization. As noted by session moderator Serhiy Semerikov in closing remarks, while the conference would continue with an Educational Technology session the following day, the Computer Science Education presentations had already provided valuable insights that would influence future research and practice.

The Computer Science Education section thus demonstrated the field's dynamic evolution in response to technological advancement and changing educational needs. From AI integration to game-based learning, from mathematical foundations to soft skills development, the research presented offers a comprehensive view of how computer science education is adapting to prepare students for an increasingly complex and interconnected digital world. The session's conclusion with warm exchanges between participants, expressing gratitude for the opportunity to share ideas despite challenging circumstances, underscored the importance of international collaboration in advancing computer science education for all learners.

4.7. Educational Technology

The Educational Technology section of ICon-MaSTEd 2025, held on May 17 as the conference's final session, featured six innovative papers that explored the transformative potential of digital technologies in education. This session brought together researchers from across Ukraine and international collaborators to address critical challenges in educational technology implementation, from intelligent systems in engineering education to augmented reality applications in laboratory work. The presentations demonstrated remarkable resilience and innovation in educational technology development despite the ongoing challenges faced by

Ukrainian educators.

The session opened with Batsurovska et al. [230] presenting “Implementation of digital technologies and intelligent systems in teaching general technical disciplines”. The authors addressed the critical need for modernizing engineering education through digital transformation, emphasizing the integration of artificial intelligence, industry collaboration, virtual laboratories, personalized learning pathways, and automation. Their experimental study involved 100 students in a control group and 101 in an experimental group participating in dual education that combines theoretical instruction with practical workplace training. The experimental group utilized digital technologies and intelligent systems during their university studies and applied these skills in workplace environments, while the control group used traditional and online forms of education. The results demonstrated significant improvements in professional competency formation among students using the integrated digital approach. During the discussion, questions arose about modifying online learning approaches for students with limited technology access, particularly in Ukrainian regions affected by conflict. The presenters emphasized the importance of developing both online and offline variants of educational materials to ensure accessibility regardless of internet connectivity.

Akhiiezer et al. [231] contributed a sophisticated technical solution with their paper on “A curriculum recommendation system using a vector database for challenge-based learning”. This innovative system employs mixed integer programming algorithms to optimize personalized curriculum recommendations based on multiple constraints, including logical sequencing and credit accumulation requirements. The authors developed a k-nearest neighbors clustering method for assessing student grades and generating performance vectors for uncompleted tasks, essential for personalizing learning recommendations. The architecture leverages vector databases to efficiently match students with appropriate challenges based on their competencies and learning objectives. The system’s ability to adapt to individual student needs while maintaining curricular integrity represents a significant advancement in personalized learning technology, particularly relevant for challenge-based learning approaches that prepare students for real-world problem-solving.

Kovtoniuk et al. [232] presented an imaginative approach to mathematics education with their “Virtual educational mathematics park as a platform for educational and research activities at the university”. This innovative project combines physical and virtual spaces to create an immersive mathematical learning environment. The authors developed 3D models of mathematical objects, including Platonic solids and other geometric structures, integrated with QR codes for augmented reality experiences. The virtual park concept extends beyond simple visualization, incorporating virtual laboratories where students can explore mathematical concepts through interactive 3D models that can be rotated, scaled, and manipulated. The project also included a proposal for a physical landscape mathematics park in Vinnytsia, demonstrating the potential for bridging digital and physical educational spaces. The authors emphasized how this approach harmoniously combines past mathematical achievements with modern digital technologies, creating platforms that serve both educational and research purposes while increasing the attractiveness of educational institutions for academic tourism.

Addressing the critical issue of pandemic and war-related educational disruption, Pronina et al. [233] presented “The use of cluster analysis in measuring educational losses”. Their research developed comprehensive software using Python’s Anaconda environment to identify and quantify learning losses among students affected by COVID-19 and ongoing military conflict. The software implements k-means and hierarchical clustering algorithms to group students with similar educational deficits, enabling teachers to develop targeted intervention strategies. Working with data from 103 students in grades 5-6 from Nikolsk Secondary School, the researchers analyzed performance in mathematics, Ukrainian language (writing), and Ukrainian literature (reading) as core indicators of educational achievement. The clustering results revealed

three distinct groups: students with consistently high scores, those with moderate achievement and significant variability, and students showing substantial learning losses requiring immediate intervention. As the presenter noted, “The teacher can predict the overall grade for the subject and timely inform parents about possible deterioration”, highlighting the tool’s predictive capabilities for early intervention.

Manziuk et al. [234] tackled the serious issue of cyberbullying with their paper on “Multifactorial analysis of mobbing behavioral signs in educational environments posts by NLP means”. The researchers developed a sophisticated natural language processing system to detect and analyze mobbing patterns in educational social media posts. Using machine learning algorithms, the system processes text from educational chat rooms and social platforms to identify potential bullying behaviors based on linguistic patterns, sentiment analysis, and contextual indicators. The experimental implementation involved real chat data, as confirmed during the Q&A when asked about practical deployment: “Yes, we take this text from text walking chats. And this is a real experiment”. The system’s ability to detect negative communication patterns in real-time offers educational institutions a powerful tool for early intervention in cyberbullying situations, contributing to safer online learning environments.

The session concluded with Kanivets et al. [235] presenting “Virtual laboratory work with augmented reality elements to teach metal hardness measurement”. This practical application addressed the challenge of conducting laboratory work during air raids when students must relocate to shelters lacking laboratory equipment. The team developed a mobile application featuring AR visualization of hardness testing equipment, including detailed 3D models of the HS-2M hardness tester created in CAD systems. The application combines theoretical content with practical simulators, allowing students to virtually operate equipment, select testing parameters, measure indenter impressions, and calculate hardness values using integrated tables. Statistical validation using Pearson’s criterion showed that experimental group students achieved quality success rates exceeding control groups by 14%, confirming the effectiveness of AR-enhanced laboratory instruction. As the presenters explained, “AR technology plays a critical role in creating interactive hybrid learning environment and developing digital skills”, particularly crucial when physical laboratory access is restricted.

Throughout the session, several unifying themes emerged that characterize the current state of educational technology in challenging circumstances. First, the necessity of developing resilient educational solutions that function despite infrastructure limitations, including intermittent internet access and displacement from traditional learning spaces. Second, the critical role of data analytics and artificial intelligence in personalizing education and identifying at-risk students. Third, the importance of immersive technologies like AR and VR in maintaining practical skill development when physical resources are unavailable. Fourth, the integration of assessment and intervention tools that enable rapid response to learning deficits.

The discussion periods revealed practical concerns about implementation, with particular attention to questions of accessibility and scalability. When asked about adapting technologies for regions with limited resources, presenters consistently emphasized the importance of developing multiple delivery modes and offline capabilities. The session also highlighted the collaborative nature of educational technology development, with several presentations featuring interdisciplinary teams combining expertise in education, computer science, and domain-specific knowledge.

As the conference’s closing session, the Educational Technology presentations demonstrated both the challenges and opportunities facing education in the digital age. The research presented offers practical solutions to immediate problems while advancing theoretical understanding of technology-enhanced learning. The session concluded with warm exchanges between participants, with acknowledgments of the importance of continuing such collaborations despite difficult circumstances. As noted in the closing remarks, these technologies are not merely temporary

solutions to crisis situations but represent fundamental advances in educational methodology that will continue to benefit learners long after current challenges have passed. The Educational Technology section thus provided both inspiration and practical tools for educators navigating the complex landscape of 21st-century education, demonstrating that innovation can flourish even in the most challenging circumstances.

5. Conclusion

The XVII International Conference on Mathematics, Science and Technology Education (ICon-MaSTEd 2025) has demonstrated that educational innovation not only persists but flourishes even in the face of extraordinary challenges. The conference proceedings, encompassing 31 rigorously selected papers across multiple educational domains, provide compelling evidence that the global educational community remains committed to advancing pedagogical excellence and ensuring equitable access to quality education regardless of circumstances. The hybrid format of the conference itself exemplified this commitment, enabling meaningful international collaboration despite physical barriers and safety concerns.

A profound transformation in educational technology integration emerged as the dominant theme across all conference sessions. The widespread adoption of artificial intelligence, augmented reality, and sophisticated digital ecosystems represents more than a temporary response to crisis conditions; it signals a fundamental reimagining of educational delivery and assessment. Papers discussing AI applications in mental health education, chatbot-mediated language learning, and vector database-driven curriculum recommendation systems demonstrate that these technologies are moving from experimental periphery to pedagogical mainstream. Particularly noteworthy is the emphasis on developing both online and offline variants of educational materials, ensuring that technological innovations remain accessible even in regions with intermittent internet connectivity or damaged infrastructure.

The conference revealed a remarkable evolution in conceptualizing 21st-century competencies, with presenters consistently emphasizing the integration of technical skills with critical thinking, visual reasoning, and adaptive problem-solving abilities. The Mathematics Education section highlighted how gamification and real-world applications can transform abstract concepts into engaging learning experiences, while the Computer Science Education presentations demonstrated the importance of developing computational thinking from early childhood. These approaches reflect a growing recognition that future-ready education must balance domain-specific knowledge with transferable cognitive and metacognitive skills. The emphasis on project-based learning, evident in multiple presentations, suggests a pedagogical shift toward more authentic, context-rich learning experiences that better prepare students for complex real-world challenges.

The resilience and innovation demonstrated by Ukrainian educators and researchers deserves special recognition. Far from being passive victims of circumstance, they have emerged as pioneers in crisis-responsive education, developing solutions that have global applicability. The development of mobile AR applications for laboratory work that can function in bomb shelters, the creation of adaptive learning systems that respond to interrupted study patterns, and the implementation of peer support networks for mental health represent innovations born of necessity but refined through rigorous research and evaluation. These contributions underscore an important principle: constraints often catalyze creativity, and the solutions developed under pressure frequently surpass those emerging from more comfortable circumstances.

The interdisciplinary nature of the conference discussions points toward a future where traditional academic boundaries become increasingly permeable. The integration of mathematics with engineering applications, the fusion of computer science with humanities education, and the application of physics concepts to environmental studies all suggest that effective education for the coming decades will require more fluid, interconnected approaches to knowledge construction.

This interdisciplinarity extends to the composition of research teams themselves, with successful projects increasingly featuring collaborations between educators, technologists, psychologists, and domain experts. Such collaborations are essential for developing holistic solutions that address not only cognitive learning objectives but also emotional, social, and practical dimensions of education.

Looking forward, the conference proceedings suggest several critical areas requiring continued attention and research. The ethical implications of AI in education, particularly concerning data privacy, algorithmic bias, and the digital divide, demand ongoing scrutiny and proactive policy development. The challenge of teacher professional development in rapidly evolving technological landscapes remains acute, with multiple presenters noting the gap between technological possibilities and pedagogical implementation. Additionally, the need for robust assessment frameworks that can evaluate both traditional academic achievements and emerging digital competencies represents an urgent research priority.

The warm exchanges and expressions of gratitude that concluded many conference sessions remind us that education remains fundamentally a human endeavor, grounded in relationships, empathy, and shared purpose. Technology serves as an amplifier and enabler, but the core mission of education – to develop human potential and foster understanding – remains unchanged. As one presenter noted in the closing session, these gatherings are essential not merely for sharing research findings but for maintaining the international solidarity that sustains educational progress even in the darkest times.

ICon-MaSTEd 2025 has provided both a snapshot of current educational innovation and a roadmap for future development. The conference demonstrates that crisis can accelerate positive change, that international collaboration transcends political boundaries, and that the educational community's commitment to serving learners remains unshakeable. As we move forward, the insights, methodologies, and technologies presented at this conference will undoubtedly influence educational practice globally, contributing to more resilient, inclusive, and effective educational systems. The journey toward educational excellence continues, informed by the remarkable contributions of all conference participants and sustained by their collective dedication to advancing human knowledge and capability.

We hope all participants enjoy this conference and meet again in a more friendly, hilarious, and peaceful way, ICon-MaSTEd 2026. The next meeting in the series is the XVIII International Conference on Mathematics, Science and Technology Education, 2026, Kryvyi Rih, Ukraine (<https://icon-masted.easyscience.education/2026/>).

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Using the case method while training would-be Mathematics teachers

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Abstract. The article looks into the issue of developing a methodology for using the case method in mathematics teacher training. The study proposes and substantiates the components of using the case method in teaching the methodological disciplines of the would-be mathematics teacher: motivation of educational activity, goal setting, content, methods, forms, and means of learning. Motivation for learning using the case method is provided by modeling the teacher's real professional activity while considering methodological problem situations (cases). To ensure goal setting, an algorithm for case selection is proposed and illustrated depending on the goal of the educational curriculum or the goal of a specific educational class. The research method is the case method, implemented through work with a system of cases for methodological disciplines. The content of the cases covers all modules of the methodological discipline curriculums. Forms of training depend on the types of cases used in the class. Examples of cases of all kinds are proposed, suitable for use within frontal, group, and individual work. Learning means include multimedia presentations, video cases, dynamic mathematics packages, and educational cloud services. The run experiment confirmed the practicality of using the developed methodology when training would-be mathematics teachers for professional activities.

1. Introduction

Modern education focuses on introducing innovative technologies to the training of teachers who can take into account the social contexts of learning and are ready to find effective ways to solve issues in the educational process [1]. As rightly pointed out by Smith and Friel [2] and Zhou et al. [3], the case method provides opportunities to bring the process of learning Mathematics as close as possible to the professional activity of a mathematics teacher, creates conditions for modeling and finding solutions to various professional issues. Professional training of would-be mathematics teachers is carried out when studying mathematical and methodical disciplines. The role of methodological discipline is leading. The main methodological disciplines are Mathematics Learning Methods, Mathematics Learning Technologies, and others. The process



of designing and modeling the professional activity of the would-be teacher goes after mastering the theoretical foundations of mathematics didactics. This makes it possible to simulate the specific situations that mathematics teachers face within their professional activities in the most detailed, systematic, and consistent manner. Therefore, the issue of the methodology of using the case method while training would-be mathematics teachers is relevant.

The general theoretical foundations of the case method in education are highlighted in the studies of Negretti and Khuder [4], Amaratunga and Baldry [5], Chang [6], and Puri [7]. Amaratunga and Baldry [5] and Chang [6] argued for the feasibility of using the case method in education. We share the scientists' opinion that the case method is effective for the development and improvement of students' abilities. A condition for this development is the sufficient standard of theoretical knowledge of the subject. Negretti and Khuder [4] considered the principles and prerequisites of using the case method when training specialists majoring in Philology and Journalism. We were fascinated by the opinions of scientists regarding the importance of the case for bringing learning as close as possible to real professional situations. Puri [7] considered the methodological aspects of using the case method for learning students majoring in economics. What is crucial for us is the scientist's statement regarding the sequence of using different cases in the educational process (from mini-cases containing the simplest problem situations to long-term complex multifactorial cases).

Various aspects of using the case method when training psychologists were studied by Herreid [8], Levin [9], and Wu et al. [10]. Levin [9] offered recommendations on organizing teachers' work with cases. We appreciated the researcher's statement about the importance of organizing a group discussion among teachers while working with cases. Herreid [8] justified the feasibility of using the case method in organizing STEM education. We were fascinated by the author's idea about the importance of using the case method to activate students' activities and increase motivation to study a certain topic of the STEM course. Wu et al. [10] considered implementing the case method in the training of psychologists. We share the opinion of scientists that the case method is effective in increasing the standard of academic students' success and it is also one of the practical methods of interactive training of would-be teachers and psychologists, tutoring them to perform professional activities, organizing collective interaction with participants in the educational process.

Separate theoretical and practical aspects of using the case method in the process of learning Mathematics at various educational institutions are highlighted in the works of Barnett [11], Sagala et al. [12], Zhou et al. [3], Siregar et al. [13], Smith and Friel [2]. Barnett [11] justified the feasibility of using the case method when training would-be mathematics teachers. The scientist's position is correct that the case method is fundamental for developing would-be teachers' cognitive and practical abilities. Sagala et al. [12] investigated the effectiveness of the case method in learning Mathematics in primary grades. It was respected that the case method contributes to developing critical thinking and the ability to justify one's opinion while learning Mathematics. Zhou et al. [3] and Siregar et al. [13] investigated the effectiveness of using the case method when teaching Mathematics to students of Mathematics majors. The scientists' conclusions confirmed that the case method contributes to the development of students' research abilities. Smith and Friel [2] considered using cases of different durations while training would-be mathematics teachers. As all mentioned authors rightly pointed out, creating a problem situation using the case method helps to increase motivation to study. Using the case method when training the would-be mathematics teacher is part of his didactic training. Issues of didactic training of the would-be mathematics teachers were the subject of research by Giacomone et al. [14], Bautista and Cipagauta [15], Díaz and Poblete [16], De Sousa et al. [17], Breda et al. [18], Blanco et al. [19], Castro and Toro [20]. Giacomone et al. [14] investigated the method of formation of didactic skills and reflective competence of the would-be mathematics teacher. Scientists have confirmed the cruciality of forming the abilities of mathematics teachers to apply

didactic skills in practice and to reflect on the acquired experience. Castro and Toro [20] investigated the method of forming the ability of mathematics teachers to argue their opinions. As scientists rightly point out, the ability to justify one's opinion, to convince students is one of the key didactic abilities of a teacher. The formation of such aptitudes is most effective in the process of organizing collective discussions during training.

Based on the views of Breda et al. [18], who noted the criticality of organizing students' contextual activities for their acquisition of didactic knowledge, Bautista and Cipagauta [15] investigated didactic trends in mathematics teacher training. It was argued that modern teacher training should be based on research and contextual activities. Díaz and Poblete [16] reported the results of a Chilean project aimed at improving students' mathematical and didactic knowledge and abilities. The opinion of scientists regarding the practicality of contextual training of would-be mathematics teachers was taken into account. De Sousa et al. [17] substantiated the importance of forming teachers' abilities to create mathematical tasks and solve problematic situations in professional activities. As scientists rightly pointed out, a modern mathematics teacher should be able to solve issue situations and adapt mathematical problems to the social order of education. Blanco et al. [19] considered the requirements for methodological and mathematical training of primary school teachers. The searchers emphasized the importance of systematic use of practice-oriented teaching methods. One of them is the case method.

The same idea is supported by Achkan et al. [21]. Scientists have singled out a classification of cases that should be used in teaching didactic disciplines. The study proposed the classification characteristics of cases: according to the amount of execution time, the way of presentation, the level of complexity, and the breadth of the covered issue.

Cases are divided into mini-cases, medium-term cases, and long-term ones, depending on the period required to complete them. According to the method of presentation, cases are divided into printed, multimedia presentations, and video ones. Respectively to the level of complexity, the cases are structured into reproductive training, partial research, and creative innovation. Regarding the breadth of problem coverage, cases are divided into thematic and integrated. The implementation of this classification involves the creation of a holistic methodology for its use in the process of training would-be mathematics teachers. Therefore, the article aims to present the methodology of using the case method while teaching methodological disciplines to would-be mathematics teachers and to confirm its implementation practicality.

2. Methods

The basis of the research method is the adoption and improvement of the general components of the methodology of learning Mathematics [21, 22] for the developing and implementing the methodology of using the case method for training the would-be mathematics teacher while learning the methodological disciplines (figure 1).

It describes each of the interrelated components of the five methodology components using the case method components presented in figure 1. The previous analysis of the scientific research has confirmed that using the case method is positively perceived by most students. The following aspects help to increase the motivation to study methodical disciplines. The case method involves consideration of specific, realistic methodological situations. Students understand that they should solve similar issues in their future professional activities. Therefore, acquired abilities are necessary. Forms of work allow students to develop their ability to debate their opinions, respect their colleagues' ideas, discuss, and work in a team. Such educational activity always catches students. Goal setting involves choosing a type of case for developing a certain competence. In addition, goal setting is focused on realizing a certain goal in a lecture, practical session, or extracurricular self-work of students. Table 1 shows examples of learning objectives and types of cases that should be used to achieve these objectives. This table also offers examples of relevant cases. At least one of the cases listed in table 1 should be used

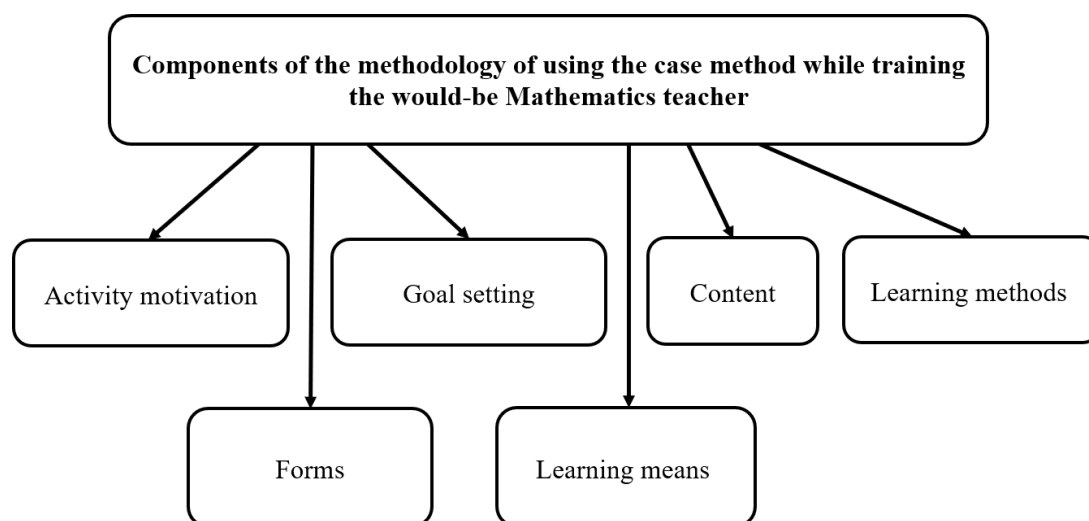


Figure 1. The methodology constituents of using the case method while learning the methodological disciplines to the would-be mathematics teacher.

systematically in all practical classes and lectures (depending on the number of lecture hours) and offered for students' extracurricular work.

The content component of the proposed methodology involves applying the case system while learning Mathematics. The content of specific cases is determined by the curriculum of a certain methodological discipline (General Methods of Learning Mathematics, Partial Methods of Learning Mathematics, Technologies of Learning Mathematics, etc.)

The main forms of work within the methodology include frontal, group, and individual. table 2 presents the types of cases, the most appropriate forms of working with them, and examples of the corresponding ones.

It is advisable to accompany the case method with multimedia presentations and videos. Moreover, it is respected to use dynamic mathematics packages (in particular, Desmos and GeoGebra) and cloud services for educational purposes. During the discussion of cases, students should justify the feasibility of using certain learning means.

3. Results

Implementing the methodology of using the case method while training would-be mathematics teachers was carried out in September-December 2023. 89 students in the 3rd-4th year of Berdyansk State Pedagogical University, Kryvyi Rih State Pedagogical University, Donbas State Engineering Academy, and Ternopil Volodymyr Hnatiuk National Pedagogical University participated in the experiment. This sample is representative, as it includes students of five universities from different regions of Ukraine and more than 15% of would-be mathematics teachers studying in their senior years. At the beginning of the experiment, the participants were randomly divided into a control group (CG) and an experimental group (EG). In the control group, 45 students studied methodical disciplines without using the case method. In the experimental group, 44 students were trained using the case method. The homogeneity of the groups at the beginning of the experiment was checked based on the results of taking diagnostic tests on methodical disciplines. The diagnostic test consisted of four traditional methodological tasks, to which one reproductive mini-case was added.

The results of taking the diagnostic tests on methodical disciplines at the beginning of the experiment are shown in table 3.

Table 1. Examples of learning objectives and corresponding types of cases.

Learning objectives examples	Types of cases	Case example
Creating an issue at the lecture	Mini-cases, re-productive and training cases, thematic, video cases, or multimedia presentations	The student-intern taught a fifth-grade math class. The topic was ‘Comparing Decimal Fractions’. At the stage of the initial consolidation of the acquired knowledge, one of the students came up with the following solution to the fraction comparison problem: $5.09 < 5.090$, since the second fraction has more fractional digits. What the teacher’s methodological explanations may help students not to repeat such mistakes in the future?
Creating an issue in the seminar on Partial Methods of Learning Mathematics	Medium-long, partially research-based, thematic, video-cases or multimedia presentations	In the 8th-grade geometry class, during a spoken question, one student claimed that the middle line of a trapezoid is the line that passes through the midpoints of its lateral sides. Another student interpreted the middle line of the trapezoid as a segment of the straight line connecting the midpoints of the trapezoid. What explanation (exercises, tasks) should the teacher suggest to help students not repeat such mistakes?
Development of basic methodological abilities	Mini-cases and medium-long cases, reproductive-training cases, partially research-based cases, thematic cases	The 10th-grade students were offered homework, which required them to calculate the value of the expression $\frac{53}{8-\sqrt{11}} + \frac{2}{\sqrt{13}+\sqrt{11}} - \frac{9}{\sqrt{13}+2}$. Solve the problem and analyze what typical mistakes students may encounter when solving such an exercise. Come up with an algorithm for composing similar numerical expressions.
Formation of research abilities	Medium and long-term cases, partially exploratory and creative-innovative cases, thematic and integrative cases	During 9th-grade geometry class, students were asked to solve a problem with an incomplete formulation: The sides of a rectangular trapezoid are equal to 13 m and 5 m. Formulate several problems using the given beginning, which can be used while learning various mathematics topics in different grades. List these topics and possible typical students’ mistakes.
Formation analysis abilities, design, and implementation of innovations in the educatory process	Long-term cases, creative and innovative cases, integrative cases	The headmaster set a task for the novice mathematics teacher. The issue was to develop an elective course for the 10th-grade students of the physico-mathematical profile and to present methodological recommendations for implementing project-based learning into studying this course. The next task was to represent any topic for the elective course and an outline of one class.

Table 2. Types of cases and corresponding forms of work with these cases.

Types of cases	The most appropriate forms of work with the case	Case example
Mini cases, re-productive training cases	Mostly frontal form of work, and, sometimes, work in groups	The teacher conducted a quick survey in the mathematics class. Students solved the following equations orally within 4 minutes: • $0.225x - x^2 = 0$; • $59x^2 + 4x - 55 = 0$; • $9x^2 + 81 = 0$; • $2x^2 + 12x + 18 = 2(x + 3)^2$. State the purpose for which the students were offered such tasks and specify the expected solutions. What are the typical issues that students may encounter when solving these equations?
Medium-long cases, partially investigative and thematic cases	Mostly group work in heterogeneous groups, sometimes frontal and individual work	When discussing the internship student work plan for the next week, the head of the internship from the higher educational institution stated the task. In your next 8th-grade elective, offer students a research assignment using the Varignon parallelogram. While completing the task, students should get an idea of the possible shapes of this parallelogram. Moreover, students should learn how to justify that the shape described in the task is a parallelogram.
Long-term cases, creative and innovative cases, integrative cases	In preference, an individual form of work, with the presentation of the solution to the group and organization of discussion, sometimes, work in pairs (threes)	The head of the school's community of Physics and Mathematics teachers suggested that the novice teacher take a report for the methodical association on the flipped learning mathematics and the use of social networks within it. To clarify the issue, the teacher should justify the feasibility of using flipped learning mathematics in high school and determine the conditions of its use and the part of social networks in this process. Moreover, the novice teacher should develop 1–2 classes to present the report.

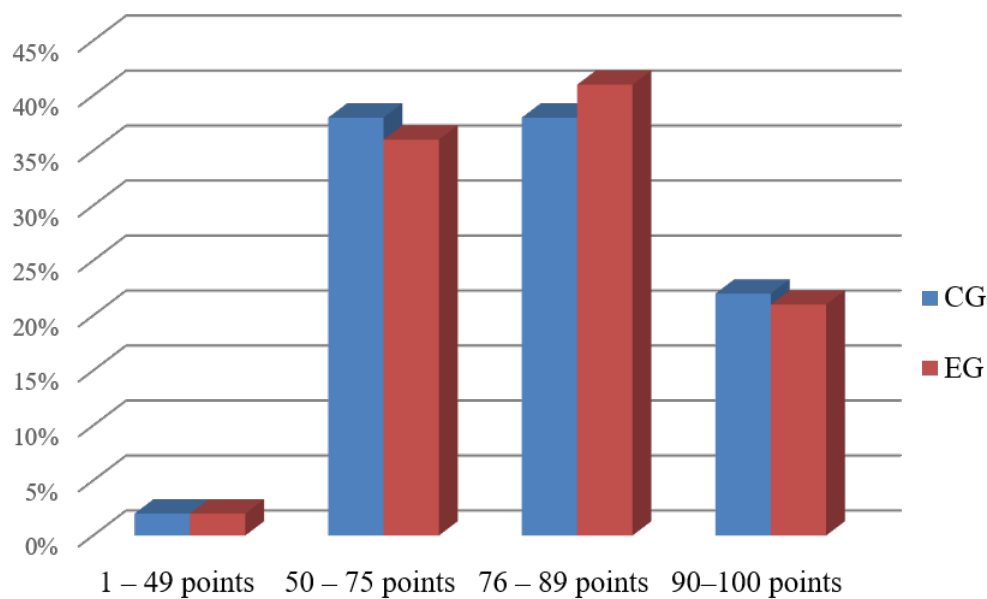
Table 3 and figure 2 show that the results of the tests in the control and experimental groups at the beginning of the experiment are almost the same. In particular, the largest difference of 3% was observed between students who scored 76-89 points in favor of the experimental group.

Given that the distribution is close to normal, the Fisher's statistical test φ^* used to confirm that the difference between the test results in the control and experimental groups was not statistically significant.

Statistical hypotheses were formulated. The null hypothesis was that students' level of skills in methodical disciplines of the control and experimental groups at the beginning of the experiment

Table 3. Results of the diagnostic tests on methodical disciplines at the beginning of the experiment.

The level of student achievement, CG				The level of student achievement, EG			
1–49 points	50–75 points	76–89 points	90–100 points	1–49 points	50–75 points	76–89 points	90–100 points
1 (2%)	17 (38%)	17 (38%)	10 (22%)	1 (2%)	16 (36%)	18 (41%)	9 (21%)

**Figure 2.** Results of taking the diagnostic tests in methodical disciplines at the beginning of the experiment.

did not differ statistically significantly.

The alternative hypothesis was that students' level of skills in methodical disciplines of the control and experimental groups at the beginning of the experiment was statistically significantly different.

The values of φ from table 4 are $\varphi_1(62\%) = 1.813$ and $\varphi_1(60\%) = 1.772$. The calculated empirical value of φ^* is 0.193. At the same time, the critical value φ^* for any n_1, n_2 , is equal to

$$\varphi_{cr.} = \begin{cases} 1.64 & (p \leq 0.05) \\ 2.31 & (p \leq 0.01). \end{cases}$$

So, after computing $\varphi_{emp.}^* = 0.193$ was gotten that $\varphi_{emp.}^* < \varphi_{cr.}^*$.

It means the null hypothesis was accepted and the alternative was rejected. Thus, the control and experimental groups were homogeneous at the beginning of the experiment.

CG students studied methodical disciplines at universities without using the case method. EG students studied methodological disciplines using the case method according to the suggested methodology.

At the end of the experiment, the students also took the tests on methodical disciplines. In addition to the traditional two methodical tasks, the tests included two cases: a reproductive mini-case and a medium-long partial search case. The results of the students' tests are shown

Table 4. Table for calculating the criterion when comparing the level of students' skills in methodical disciplines at the beginning of the experiment.

Group	Scored from 76 to 100	Scored from 1 to 75	Together
Control	27 (60%)	18 (40%)	45
Experimental	27 (62%)	17 (38%)	44
Together	54 (100%)	35 (100%)	89

in table 5 and figure 3.

Table 5. Table for calculating the criterion when comparing the level of students' skills in methodical disciplines at the end of the experiment.

Group	Scored from 76 to 100	Scored from 1 to 75	Together
Control	29 (65%)	16 (35%)	45
Experimental	38 (86%)	6 (14%)	44
Together	67 (100%)	22 (100%)	89

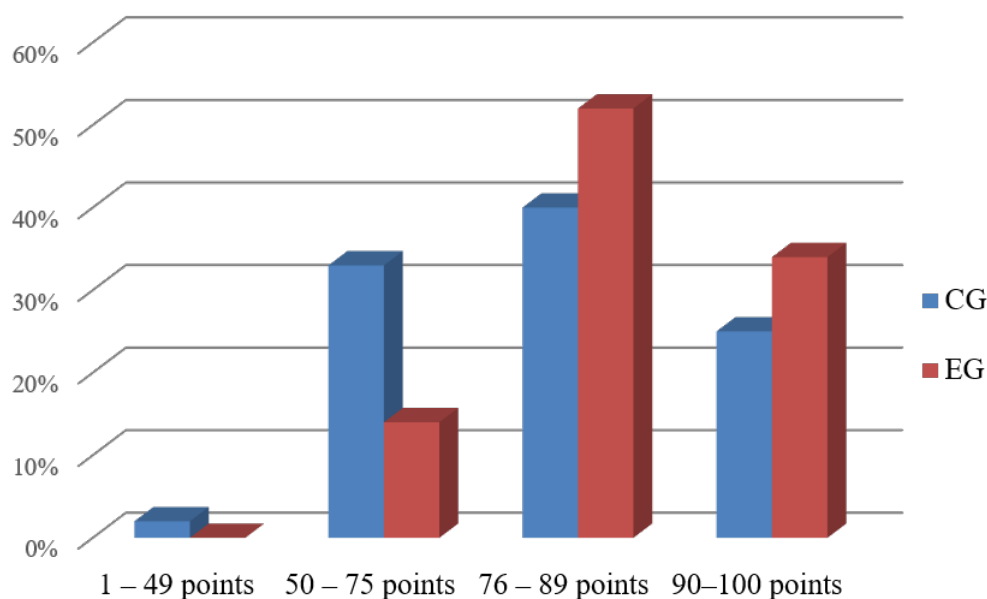


Figure 3. Results of the students' tests on methodical disciplines at the end of the experiment.

Table 5 and figure 3 show that the results of the control tests in the control and experimental groups differ significantly at the end of the experiment. In particular, the largest difference of 19% was observed between students who scored 50-75 points in favor of the control group, while 12% was observed between students who scored 76-89 points in favor of the experimental group.

Given that the distribution is close to normal, the Fisher's statistical test φ^* used to ensure that the difference between the control results in the control and experimental groups was statistically significant. Statistical hypotheses were formulated, and according to the null

hypothesis, the level of skills in methodical disciplines in the control and experimental groups at the end of the experiment did not differ statistically significantly.

The alternative hypothesis was that the level of skills in methodological disciplines in the control and experimental groups at the end of the experiment was statistically significantly different.

The angles determination according to table 5 are $\varphi_1(86\%) = 2.375$ and $\varphi_2(65\%) = 1.875$. Hence, the empirical value of φ^* is 2.36. The critical value φ^* for any n_1, n_2 is determined by (3). So, after calculating $\varphi_{emp.}^* = 2.36$ was gotten that $\varphi_{emp.}^* > \varphi_{cr.}^*$.

Since $\varphi_{emp.}^* > \varphi_{cr.}^*$, the null hypothesis was rejected, and the alternative hypothesis was accepted. Thus, the level of student skills in methodical disciplines in the control and experimental groups is statistically significantly different. The data presented in table 6 give reasons to assert that the level of student skills in methodical disciplines in the experimental group is higher than in the control group.

Table 6. Results of the tests on methodical disciplines at the end of the experiment.

The level of student achievement, CG				The level of student achievement, EG			
1–49	50–75	76–89	90–100	1–49	50–75	76–89	90–100
points	points	points	points	points	points	points	points
1 (2%)	15 (33%)	18 (40%)	11 (25%)	0 (0%)	6 (14%)	23 (52%)	15 (34%)

Statistically, the verification based on the control test results allows us to assert the practicality of using the case method while training the would-be mathematics teacher.

4. Discussion

As rightly pointed out by Herreid [8], Arseven [23], and Amaratunga and Baldry [5], in modern higher education, the cruciality of modeling future professional activity is growing both in the process of practical and the process of theoretical activity. This is consistent with the findings of Díaz and Poblete [16], who claim that one of the effective methods of detailed and systematic modeling of specific situations that mathematics teachers may encounter in their professional activities is the case method. Its use requires the development of a certain methodology.

The basis of the stated methodology development is the classification of cases from methodological disciplines, which was introduced by Achkan et al. [21]. Following Vlasenko et al. [22], the methodology describes its components, such as activity motivation, goal setting, content, methods, forms, and means of learning. The motivation to work with cases is related to solving methodological issues that mathematics teachers face in their professional activities.

Types and specific examples of cases are picked out, which are practical to use, ensuring students' goal-setting. In particular, to create a problematic situation at lectures, it is advisable to use mini-cases, reproductive-training cases, and thematic and video cases. To develop students' research abilities, it is advisable to use medium and long-term cases, partially exploratory and creative-innovative, thematic, and integrative cases.

The method in the article is the case method, which is implemented through work with the system of cases from methodological disciplines. The content of the cases covers all modules of the methodological discipline programs: General Methods of Learning Mathematics, Partial Methods of Learning Mathematics, Technologies of Learning Mathematics, and others.

Forms of learning within the offered methodology are determined depending on the type of case considered in the training of the would-be mathematics teacher. In particular, while working with mini-cases and reproductive training cases, it is advisable to use the frontal form of work and, in some cases, work in groups. When working with long-term, creative-innovative,

and integrative cases, it is worth using an individual form of work, and, in some cases, it can be in mini-groups. It is expedient to include multimedia tools for presenting cases, dynamic mathematics packages, and cloud services as learning means. There may be difficulties in using cases due to the need for extra time for students' classroom work when studying methodological disciplines.

5. Conclusions

The analysis of scientific works confirmed the relevance of the study of the methodology of using the case method when training the would-be mathematics teacher. The basis of this methodology is the classification of cases depending on the amount of time for execution, the level of complexity, the breadth of coverage of the problem, and the way of presentation.

It was established that the first component of the methodology - motivation for educational activity is provided thanks to the modeling of the real professional activity of the teacher when considering methodological problem situations (cases) within the case method. The next component of the methodology is goal setting. The study proposed and illustrated the case selection algorithm depending on the purpose of the curriculum or the purpose of a class.

The experiment confirmed that when choosing forms of learning within the implementation of the case method, it is advisable to focus on the types of cases used in the class. The study offered cases of all kinds that are practical to use within frontal, group, and individual forms of work. The use of multimedia presentations, video cases, dynamic mathematics packages, and cloud services for educational purposes are also offered and tested within the introduction of the case method. At the same time, the emphasis in training was on the practicality and methodical advantages of using certain educational means while finding a solution and presenting the results. Experimental verification of the case method implementation using diagnostic control tests confirmed its practicality while training the would-be mathematics teacher for professional activity.

We see the adaptation of the developed methodology in improving the qualifications of mathematics teachers as a vector for further research.

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Application of the Cobb-Douglas function for the formation of would-be economists' analytical skills

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Abstract. Training high-quality specialists in the economic field is crucial. This task can be achieved by training students in economic specialties in mathematical modeling. Solving problems using production functions, particularly Cobb-Douglas functions, can become the ground for mastering mathematical modeling. The article looks into the issue of the combination of table and clustering methods to systematize such kinds of problems. The involvement of students in real production situations while mathematical training contributes to the development of analytical skills needed for analyzing economic processes, modeling decisions, working with data, and coming to conclusions. The article presents a system of problems involving the Cobb-Douglas production function. The study shows the implementation of these problems while mastering 'Multivariate Functions' by economic majors. Also, the work presents the practicality of such a system when developing their analytical skills. The run experiment confirmed that the developed system of problems results in the progression of would-be economists' analytical skills.

1. Introduction

There is always an urgent issue of training economists whose skills will be able to ensure stable development in any country. When preparing such specialists, they should be taught mathematical modeling, which means that they should understand in practice how to build a mathematical model of a real problem and solve it with the help of a mathematical apparatus. Creating economic models that characterize the dependence of the volume of production on various factors or their ratios in the conditions of the national economy requires applying production functions. Such models usually contain the production volume in natural or value terms and spent volumes of resources. They are called factors of production. There are two types of production functions:



- (i) single-factor, establishing the dependence of the volume of production on one factor; this variety includes linear, parabolic, static, and indicative functions;
- (ii) two-factor establish the dependence of the production volume on the ratio of two factors; this variety includes Cobb-Douglas, Leontiev, Solow, and Allen functions.

The Cobb-Douglas function belongs to the class of two-factor production functions. For this function, capital and labor are chosen as the two main factors of production. A certain proportionality of their combination creates conditions for obtaining a product. The purpose of the Cobb-Douglas production function is to reflect the technological ratio of the labor input and capital required to produce a particular product in the required quantity.

The concept of a production function, which relates output to the factors that underlie it, has a long history. In the early 1900s, economists used that idea to explain phenomena ranging from diminishing returns to exhaustion of the product under conditions of maximum productivity. Malthus' iron law of wages, Ricardo's theory of rent, the trend of the relative share of income in a developing economy, the first-order conditions for optimal factor employment, and Euler's addition theorem – all based on the Cobb-Douglas production function [1]. For the first time, the Cobb-Douglas function was used by the Swedish economist Knut Veksell. Its statistical verification was performed from 1927 to 1947 by two scientists – Charles Cobb and Paul Douglas [2]. The production function developed by Cobb and Douglas is the first aggregate production function. Its application made it possible to model both small-scale processes and entire sectors of the economy. Statistical confirmation of this function was the beginning of a new stage of macroeconomic development, which allows the assessment of the efficiency of production at the standard of the national economy.

The literature analysis results in the conclusion that the Cobb-Douglas production function is used to estimate the production capacity of the economic sector in different countries of the world. Skrynkovskyy et al. [3] used the Cobb-Douglas production function to forecast trends in the state's industrial development using the example of Ukraine. Rana et al. [4] highlighted the methods of raising domestic animals and the socio-economic conditions for this in the example of Cuchia farmers in the Bogura district of Bangladesh. The Cobb-Douglas production function was used to determine the contribution of the most important variables in the production process of Cuchia farming. Tirfi and Oyekale [5] analyzed the influence of some climatic variables on the yield of maize in Ethiopia. Augmented Cobb-Douglas production function was used for data analysis.

Jandhana et al. [6] devoted their research to assessing and analyzing the sustainability of the metallurgical sector in Indonesia using the Cobb-Douglas production function. The analysis shows how labor costs, capital investment, and total factor productivity contribute to industry growth. This study and its results contributed to the enlargement of sustainability measurement research in the metallurgical sector and other industries. The German economist Koch [7] believes that the Cobb-Douglas production function is central to economic growth theory and microeconomics. Convenient mathematical properties explain its use. Some of these properties describe a set of (partial) differential equations.

Despite the Cobb-Douglas function applicability, there is debate as to whether its analytical form makes sense from a dimensional point of view. Economist Labini [8] joined the discussion and noted that despite several harsh criticisms, the function should be used 'in the first approximation'. Mathematician Vilcu [9] obtained an interesting connection between some fundamental concepts in the theory of production functions and the differential geometry of hypersurfaces in Euclidean spaces. He established that the generalized Cobb-Douglas production function has decreasing/increasing returns to scale if and only if the corresponding hypersurface has positive/negative Gaussian curvature. Furthermore, this production function has constant returns to scale if the corresponding hypersurface can be developed. By defining the Cobb-Douglas function with variable output elasticity, it can be shown that a large class of production

functions can be written as the Cobb-Douglas function with non-constant output elasticity. This framework has several advantages in contrast with standard flexible functions such as the Translog function. Its inclusion does not require using the second-order approximation, facilitating the deduction of the linear function of input demands without invoking the duality theorem. This makes it possible to generalize the demand elasticity function understandably to the case where the elasticity of substitution between each pair of inputs is not necessarily the same. Also, it provides a more general and flexible structure compared to the traditional approach of nested elasticity functions while facilitating the analysis of substitution properties of nested elasticity functions [10].

Experimental studies rarely address the shape and nature of the production function, which is useful for obtaining optimal levels of resource substitution in increasingly resource-constrained environments. For example, the function of educational production can be investigated [11] due to the rapid spread of online education as a replacement for traditional, against the background of full-scale temporary replacement due to the coronavirus pandemic. The results show that the estimates are consistent with the general form of the Cobb-Douglas production function and imply that the blended learning approach is optimal. Conclusions [11] result in the rapid expansion of educational technologies worldwide and their continued replacement of traditional education.

Therefore, the presented conclusions show that the Cobb-Douglas production function keeps a crucial place in economic research, so its study in mathematics classes while training students in economics major does not raise doubts. Methodists Smeureanu and Isaila [12] believe that thanks to the visualization of fundamental concepts from the field of economic and mathematical modeling, it is possible to organize knowledge in coherent scenarios presented in the form of an educational game to attract attention and influence the spirit of competition of students and thus stimulate their imagination, which is used to build mental models, and intuition, which is capitalized in the process of discovering knowledge while solving a certain system of problems.

Such scientists as Landgärds [13], Hoag and Benedict [14], Semenenko and Tsibulya [15] devoted their works to the fundamental training of students of economic specialties through the involvement of a system of problems. All of them emphasize that the high-quality training of such specialists is provided by developing their mathematical literacy and knowledge of functions. After all, economists have to deal with large data sets, visually interpret data, with numbers, and with mathematical models and functions. Therefore, learning mathematical modeling is based on the mastery of functions. The elementary function consideration begins with elementary ones and moves on to studying bivariate functions. Function mastery is ensured by solving a certain system of problems. Analysis of articles [13, 14, 16]) testifies to a wide range of applications of problem systems when learning functions and mathematical modeling with their help. These are the most common application areas of such

1. Optimization of production processes: solving the problems of production optimization, resource allocation, and planning of production processes.
2. Project management: using problem systems to plan, control, and evaluate various aspects of projects in diverse industries, including construction, information technology, and research and development.
3. Logistics and supply chains: solving the problems of optimization of supply chains, distribution of goods and resources, routing, and inventory.
4. Transport and transport systems: using problem systems to develop efficient and optimal transport routes, planning traffic schedules, and managing transport networks.
5. Finance and banking: solving problems of managing portfolios, risks, and financial planning with the help of problem systems.

6. Medicine and health care: using problem systems to optimize treatment processes, allocate resources in medical facilities, and plan health services.
7. Energy and resource conservation: solving energy management problems, optimizing using resources, and developing energy conservation strategies.

These areas are just examples of the problem systems application while learning using mathematical modeling. Nunokawa [17] determined the relationship between problem-solving and learning mathematics. He emphasized that choosing the right problems is crucial to providing students with an opportunity for ‘authentic’ problem-solving. Caerols and Vogt-Geisse [18] gave examples of problems to motivate students’ critical mathematical thinking while learning Mathematics. Lubienski [19] focused on improving students’ intellectual abilities in mathematics education through problem-solving. Al-Khateeb [20] devoted his work to checking the impact of solving mathematical problems using mobile learning on students’ ability to develop analytical and mathematical skills. Klang et al. [21] confirmed that solving mathematical problems is a paramount area of mathematics learning and emphasized the need for research into such approaches to mathematics learning. Jacinto [22] substantiated that solving mathematical problems while training would-be economists causes the student’s interest to rise and improve their mathematical skills and specific abilities. So, the research analysis proved that a correctly selected system of problems for the production functions application, particularly the Cobb-Douglas functions, while training students of economic specialties, will allow us to increase their motivation and develop their analytical, mathematical, intellectual, economic, and financial abilities.

Mathematical training for students majoring in economics is aimed at developing various skills and abilities that are important for analyzing economic processes, modeling decisions, and working with financial data. One of the crucial is analytical skills: students learn to understand, analyze, and solve complex mathematical problems related to economic theories and models. Analytical skills include a person’s ability to understand, analyze, and draw conclusions based on available information. This includes identifying relationships between facts, distinguishing the important from the minor, formulating and testing hypotheses, and making informed decisions.

Dendir et al. [23] emphasize the urgency of developing the analytical skills of students of economic specialties. Scientists believe that analytical skills form the basis for students’ problem-solving ability. Suciu and Lacatus [24] believe that developing students’ analytical skills during their economic education can be crucial for evolving an economist’s career in the new context of a knowledge-based society.

The main aspects of analytical skills include: the ability to understand context (the ability to analyze a situation or problem in a broad context, taking into account all the factors that can affect it); logical thinking (the ability to build logical arguments, develop consistent evidence and exclude unfounded assumptions); data analysis (ability to effectively process and interpret large amounts of information using various methods of data interpretation); problem solving (the ability to identify problems, set specific goals for solving them, and find optimal ways to achieve these goals); critical thinking (the ability to evaluate ideas, evidence, or decisions using objective criteria and avoiding biases or reinforcing stereotypes); decision-making (the ability to consider alternatives, gather enough information for an informed choice and draw conclusions); communication of results (the ability to clearly and effectively express one’s thoughts and analytical findings in written or oral form). There is an opinion that analytical skills can be improved by solving mathematical problems, during which new methods of analysis are taught, mathematical modeling skills are improved, and sound economic decisions are made. The validity of this opinion can be verified by developing a system of problems based on the use of the Cobb-Douglas production function.

Therefore, the purpose of our article is to systematize problems that present the use of the Cobb-Douglas production function, to implement this system of problems when

the mathematical training of economic majors, as is also to check the practicality of its implementation while developing students' analytical skills.

2. Methods

There are many methods of systematizing problems, and the choice of a specific one depends on the nature of the problem, its complexity, and specific goals. Here are some of them:

- *Classification by features or characteristics.* This method refers to grouping problems by common specifics. For example, problems can be classified by topic, difficulty, solution time, etc.
- *Method of analogies.* In this method, problems are systematized by finding analogies between them. If two problems have similar aspects or solutions, they can be combined into one category.
- *Hierarchy method.* This method uses a hierarchical structure to systematize problems. Problems are divided into groups according to their level of generality or specificity.
- *Method of matrices or tables.* Problems can be systematized by creating matrices or tables, where one axis is responsible for one or more criteria, and the other is for different tasks. This method helps compare problems according to various aspects.
- *Method of schemes or diagrams.* Using diagrams or charts can help organize problems by visualizing the relationships between them or their characteristics.
- *Ranking method.* Problems can be organized by ranking them according to certain criteria, such as importance, priority, or impact on organizational goals.
- *Method of grouping or clustering.* Problems can be organized by dividing them into groups or clusters based on their similarities.

These methods can be used separately or in combination depending on the specific situation and the needs of problem systematization. This study uses a combination of methods. It is about tabular and clustering methods. Problems presented in the table should ensure the development of students' analytical skills while mastering the section 'Multivariate functions'.

It will describe what students need to know about the Cobb-Douglas function to work with it. The Cobb-Douglas production function formula reflects the dependence of the volume of production of a certain product on the combination of two factors of production – labor (L) and capital (K). In general, the formula looks like this:

$$Q = c \cdot K^\alpha \cdot L^\beta, \quad Q : \mathbb{R}^+ \times \mathbb{R}^+ \rightarrow \mathbb{R} : (K, L) \rightarrow Q(K, L), \quad (1)$$

where Q is an indicator of the production quantity, which characterizes the real cost of goods and services produced in a certain period; c – general index of technological factor productivity; this indicator is the most difficult to determine and predicts, with a certain level of error, the possibility of imperfect assessment of labor and capital input, and even the influence of other factors; L – labor costs, which are included in the production of a certain production quantity, expressed in the number of man-hours worked by all employees for the specified period; K – costs of invested capital in the production of a certain production quantity, expressed in the real cost of equipment and machines used in production; α – technological capital elasticity; β is the technological labor elasticity.

Sometimes, the Cobb-Douglas function is simplified to a form called a partial case of the function:

$$Y = c \cdot K^\alpha \cdot L^{1-\alpha}. \quad (2)$$

This formula is used when the technological capital elasticity and labor are related: $\beta = 1 - \alpha$.

Working with production functions, students should master certain topics of ‘Multivariate functions’, namely: domain of a bivariate function, partial derivatives and first-order differentials of a bivariate function, complete increment and complete differential of the first order, derivative in direction, gradient of a function, differentiation of complex functions, partial derivatives and differentials of higher orders, differentiation of implicit functions, extremum of a bivariate function, method of least squares, etc.

It is assumed that while studying production functions, students will master not only mathematical concepts but also economic ones: average labor productivity (the ratio of the production quantity (in terms of value) to the amount of labor expended), average return on funds (quantity of products (in terms of value) per unit of funds); capital equipment, which expresses the volume of fixed assets per employee; marginal labor productivity (equal to the additional value of products created by a supplemental unit of labor); marginal return on funds (equal to the supplemental value of products produced as a result of an increase in funds per unit); isoquant or production indifference curve (a line at each point of which different combinations of production factors (capital and labor) give the same amount of output). The formulation of these concepts should be presented when considering the problems in which they are involved.

Table 1 presents a system of problems based on the Cobb-Douglas function. It contains topics of Calculus, necessary skills and related problems. The ideological complexity of the problems increases, which contributes to the gradual development of students’ skills in studying production functions and economic concepts and meets the didactic requirements for the system of problems.

Table 1: A system of problems based on the Cobb-Douglas function involvement.

№	Topics of Calculus	Skills	Problems
1	The domain of a bivariate function, the full increment of a bivariate function	The ability to identify problems, set specific goals for solving them, and find optimal	The production function is the Cobb-Douglas function. To increase output by 3%, it is necessary to either increase funds by 6% or the number of employees by 9%. In 2020, one employee produced goods worth 500 thousand conventional units (c. u.) per month. 8,000 employees work at the enterprise in c. u. The fixed capital is estimated at 1 bln. c. u. Find the production function
2	Partial derivatives of a bivariate function and its differentials of the first order, differentiation of complex functions	The ability to analyze the situation in a broad context, concerning all the factors that can affect it	There is a production function $Y = 2K^{0.2}L^{0.8}$. Find the marginal rate of displacement of capital by labor

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Nº	Topics of Calculus	Skills	Problems
3	Partial derivatives of a bivariate function and its differentials of the first order, differentiation of complex functions, partial derivatives, and higher orders differentials, differentiation of implicit functions	The ability to evaluate alternatives, the ability to gather enough information to make a justified choice and draw conclusions, the ability to clearly and effectively express one's thoughts and analytical findings in written or oral form	The production function of an enterprise is the Cobb-Douglas function. To increase output by 1%, raising funds by 3% or the number of employees by 3% is necessary. The enterprise employs 1,000 workers, and one employee manufactures products in 10^7 c. u. The fixed assets of the enterprise are estimated at 10^9 c. u. Find the production function, the average and marginal values of labor productivity and return on capital, and the elasticity of output by labor and capital. Explain the economic meaning of these indicators
4	Partial derivatives of a bivariate function and its differentials of the first order, differentiation of complex functions, partial derivatives and higher orders differentials, differentiation of implicit functions	The ability to construct logical arguments, the ability to develop a consistent proof, exclude unfounded assumptions, the ability to evaluate ideas or decisions using objective criteria, and avoid stereotypes	The quantity of a firm's production of computer monitors is expressed in terms of the input's capital K and labor L by the Cobb-Douglas production function P : $\mathbb{R}^+ \times \mathbb{R}^+ \rightarrow \mathbb{R} : (K, L) \mapsto rK^{\frac{1}{2}}L^{\frac{1}{2}}$. The firm controls the parameter $r \in \mathbb{R}_0^+$ through the technology used in the production process. The price of a unit of capital is p euro, and that of a unit of labor is q euro with $p, q > 0$. Suppose that the firm keeps its total production and its total cost constant. To achieve this, the firm currently invests K^* units of capital and L^* units of labor while the production process parameter is r^* . Moreover, $qL - pK > 0$ in a neighborhood of (K^*, L^*, r^*) . Determine the impact of an increase of the parameter r with one unit on the inputs K and L . Do this by applying the implicit function theorem and calculating the necessary derivatives with respect to r

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Nº	Topics of Calculus	Skills	Problems
5	Partial derivatives of a bivariate function and its differentials of the first order, complete increment and complete differential of the first order, derivative in direction, differentiation of complex functions, partial derivatives	The ability to evaluate alternatives, the ability to gather enough information for a reasoned choice and draw conclusions, the ability to identify problems, set specific goals for their solution, and find optimal ways to achieve these goals	The quantity of a firm's production of computer monitors (CM) is expressed in terms of the input's capital K and labor L by the Cobb-Douglas production function P_{PM}: $\mathbb{R}^+ \times \mathbb{R}^+ \rightarrow \mathbb{R} : (K, L) \mapsto rK^{\frac{1}{2}}L^{\frac{1}{2}}.$ The same firm also produces TV screens in a quantity that is analogously expressed in terms of the input's capital K and labor L by the Cobb-Douglas production function P_{PM}: $\mathbb{R}^+ \times \mathbb{R}^+ \rightarrow \mathbb{R} : (K, L) \mapsto sK^{\frac{1}{2}}L^{\frac{1}{2}}.$ The firm controls the parameters $r, s \in \mathbb{R}_0^+$ independently of each other through the technology that is used in the production process. The price of a unit capital is p euro, and that of a unit labor is q euro with $p, q > 0$. Suppose that the firm keeps its total production and its total cost constant. To achieve this, the firm currently invests K^* units of capital and L^* units of labour while the production process parameters are r^* and s^*. Moreover, $qL^* - pK^* > 0$. Determine the impact of an increase of the parameter r with one unit on the input capital if the parameter s is kept constant
6	Partial derivatives of a bivariate function and its differentials of the first order, differentiation of complex functions, partial derivatives, and higher orders differentials	The ability to analyze the situation in a broad context, concerning all the factors that can affect it	The production output q of a firm is determined by capital K and labour L. The exact relation is unknown. However, experience has shown that • a decrease of production by 3% is to be expected when capital and labour are both reduced by 1%; • an increase of production by 2% is expected when capital is decreased by 1% and labour is increased by 3%. Management wants to cut wages and plans to reduce labour by 3%. If the current production level has to be maintained, what action should management take with respect to capital?

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№	Topics of Calculus	Skills	Problems
7	Partial derivatives of a bivariate function and its differentials of the first order, differentiation of complex functions	The ability to create logical arguments, develop a consistent proof, and exclude unfounded assumptions	Work out the demand price elasticity for the Cobb-Douglas production function is given as a function of time: $Y(t) = A \cdot K(t)^\alpha \cdot L(t)^{1-\alpha}$
8	Partial derivatives of a bivariate function and its differentials of the first order, complete increment and complete differential of the first order, differentiation of complex functions, partial derivatives and differentials of higher orders, differentiation of implicit functions	The ability to evaluate alternatives, the ability to gather enough information for a reasoned choice and draw conclusions	Applying the Cobb-Douglas function for Beiersdorf AG, find the marginal productivity of labor and capital using their financial reports https://www.beiersdorf.com/
9	Partial derivatives of a bivariate function and its differentials of the first order, complete increment and complete differential of the first order, differentiation of complex functions	The ability to create logical arguments, develop a consistent proof, and exclude unfounded assumptions	Find the demand price elasticity for the Cobb-Douglas production function for BASF using their financial reports https://www.basf.com/ua/
10	The domain of a bivariate function, partial derivatives of a bivariate function and its differentials of the first order, differentiation of complex functions	The ability to create logical arguments, develop consistent proof, and exclude unfounded assumptions	Work out the Cobb-Douglas elasticity of substitution for Beiersdorf AG using their financial reports https://www.beiersdorf.com/

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№	Topics of Calculus	Skills	Problems
11	Partial derivatives of a bivariate function and its differentials of the first order, differentiation of complex functions, partial derivatives, and higher orders differentials, differentiation of implicit functions	The ability to create logical arguments, develop a consistent proof, and exclude unfounded assumptions	Consider a firm whose production can be modeled using such a production function, i.e., $q(K, L) = CK^\alpha L^\beta$ with capital denoted by K , labor by L and C , $\alpha, \beta \in \mathbb{R}_0^+$. Additionally, denote the unit price of capital and labor by w_K and w_L , respectively, and the unit price of production by p . All these prices are assumed to be positive. Then we can figure out the optimal input combination that maximizes profit. The profit function $\pi = \mathbb{R}^+ \times \mathbb{R}^+ \rightarrow \mathbb{R} : \pi(K, L)$ is determined by $\pi(K, L) =$ $= pq(K, L) - w_K K - w_L L =$ $= pCK^\alpha L^\beta - w_K K - w_L L$
12	The domain of a bivariate function, partial derivatives of a bivariate function and its differentials of the first order, complete increment and complete differential of the first order, derivative in direction, differentiation of complex functions, partial derivatives, and higher orders differentials, extremum of a bivariate function	The ability to create logical arguments, the ability to effectively process and interpret large amounts of information using various methods of data interpretation	A sample of data that characterizes the company's work over the past 10 months is given. In this sample, each value of $Y = \{157; 208; 254\}$ – the cost of manufactured products, thousand c.u. correspond to indicators $X_1 = \{11.45; 12.31; 16.20\}$ – the price of the main production assets, thousand c. u., and $X_2 = \{20.1; 25.3; 31.1\}$ – labor costs, man-hours. It is necessary to build a multiple correlation economic model in the form of the Cobb-Douglas function, evaluate the accuracy and reliability of the model, determine the closeness of the relationship between factors, construct isoquants of interchangeability of model factors, and make an economic analysis of the obtained results according to all known production functions characteristics
13	Partial derivatives of a bivariate function and its differentials of the first order, partial derivatives, and higher orders differentials	The ability to create logical arguments, develop a consistent proof, and exclude unfounded assumptions	Calculate the Cobb-Douglas production function elasticity $Y = AK^\alpha L^{1-\alpha}$ at an arbitrary point $M_0(K_0, L_0)$ in terms of the variables K and L

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№	Topics of Calculus	Skills	Problems
14	Partial derivatives of a bivariate function and its differentials of the first order, partial derivatives and higher orders differentials, extremum of a bivariate function	The ability to create logical arguments, the ability to analyze a situation or problem in a broad context, concerning all factors that may affect it	Consider the Cobb-Douglas production function. To increase production by 3%, it is necessary to increase production assets by 6% or the number of workers by 9%. Last year, one worker produced products worth 1 million c. o. per month, and there were 1,000 employees in the enterprise. Fixed assets were estimated at 10 billion c. u. Write down the expression for the production function and find the average return on assets
15	Partial derivatives of a bivariate function and its differentials of the first order, differentiation of complex functions, partial derivatives, and higher orders differentials, extremum of a bivariate function	The ability to analyze a situation or problem in a broad context, concerning all factors that may affect it, the ability to create logical arguments	For the Cobb-Douglas production function $y = 1000K^{\frac{1}{2}}L^{\frac{1}{3}}$, find the average and marginal labor productivity, the average and marginal return on capital, and the output elasticities for labor and capital
16	The domain of a bivariate function, partial derivatives of a bivariate function and its differentials of the first order, differentiation of complex functions, partial derivatives, and higher orders differentials	The ability to effectively process and interpret large amounts of information using various methods of data interpretation	Construct a Cobb-Douglas production function given a date in capital changes (X) and a date in labor changes (Y): $X = \begin{pmatrix} 8.35 & 9.58 & 10.45 & 11.57 \\ 4.93 & 6.15 & 8.47 & 8.89 \end{pmatrix},$ $Y = (65.94 \ 55.17 \ 79.12 \ 82.96).$ Construct a mathematical model of the problem by applying the Cobb-Douglas production function

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№	Topics of Calculus	Skills	Problems																																																						
17	The domain of a bivariate function, complete increment and complete differential of the first order, derivative in direction, the gradient of a function, partial derivatives and higher orders differentials, differentiation of implicit functions, least squares method	The ability to create logical arguments, the ability to clearly and effectively express one's thoughts and analytical conclusions in written or oral form	A company needs to produce 100 units of output. This amount can be produced using the following production factor combinations: <table><tr><td>L</td><td>10</td><td>6</td><td>3</td><td>1</td></tr><tr><td>K</td><td>2</td><td>7</td><td>13</td><td>16</td></tr></table> The cost of a labor unit is 100 c. u., and the capital unit cost is 60 c. u. Which of the combinations of these two factors is the most appropriate? Suppose that the labor unit cost has increased to 110 c.u. What should be the entrepreneur's decision?	L	10	6	3	1	K	2	7	13	16																																												
L	10	6	3	1																																																					
K	2	7	13	16																																																					
18	The domain of a bivariate function, partial derivatives of a bivariate function and its differentials of the first order, complete increment and complete differential of the first order, derivative in direction, the gradient of a function, differentiation of complex functions, partial derivatives, and higher orders differentials, extremum of a bivariate function, least squares method	The ability to effectively process and interpret large amounts of information using various methods of data interpretation, the ability to create logical arguments, and the ability to clearly and effectively express one's thoughts and analytical conclusions in written or oral form	A firm that produces televisions chooses one of three production technologies, each different in the combination of resources. <table><tr><th rowspan="3"></th><th colspan="6">Technologies</th></tr><tr><th colspan="2">A</th><th colspan="2">B</th><th colspan="2">C</th></tr><tr><th>L</th><th>K</th><th>L</th><th>K</th><th>L</th><th>K</th></tr><tr><td>1</td><td>12</td><td>4</td><td>9</td><td>6</td><td>7</td><td>8</td></tr><tr><td>2</td><td>22</td><td>5</td><td>13</td><td>10</td><td>11</td><td>12</td></tr><tr><td>3</td><td>32</td><td>6</td><td>17</td><td>14</td><td>15</td><td>16</td></tr><tr><td>4</td><td>44</td><td>7</td><td>21</td><td>18</td><td>19</td><td>21</td></tr><tr><td>5</td><td>62</td><td>8</td><td>27</td><td>24</td><td>23</td><td>37</td></tr></table> 1. Determine which technology the firm will choose for each production. 2. Calculate the total costs for each level of production. 3. Suppose the labor cost per unit increases to 300 c.u., and the capital cost does not change. Will this change affect the choice of technology?		Technologies						A		B		C		L	K	L	K	L	K	1	12	4	9	6	7	8	2	22	5	13	10	11	12	3	32	6	17	14	15	16	4	44	7	21	18	19	21	5	62	8	27	24	23	37
	Technologies																																																								
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№	Topics of Calculus	Skills	Problems																		
19	The domain of a bivariate function, partial derivatives of a bivariate function and its differentials of the first order, complete increment and complete differential of the first order, derivative in direction, the gradient of a function, differentiation of complex functions, partial derivatives, and higher orders differentials, extremum of a bivariate function, differentiation of implicit functions, extremum of the bivariate functions, least squares method	The ability to effectively process and interpret large amounts of information using various methods of data interpretation, the ability to create logical arguments, and the ability to clearly and effectively express one's thoughts and analytical conclusions in written or oral form	A firm produces T-shirts using L manual labor and K equipment. 1. The production function is as follows: $y = K \cdot L$. Determine all combinations of factor inputs producing 100 T-shirts. 2. The firm pays employees a wage of $w = 4$, and the use of equipment costs $r = 1$. How many factors of production can the firm consume at total costs $C = 50$? 3. What combination of factors minimizes the cost of producing 100 T-shirts? 4. What will be the maximum level of output at maximum costs $C = 400$? 5. How will this combination change if the wage rate decreases to $w = 1$? Fill in the table. Labor cost – 8 c. u. per unit. Capital cost – 12 c. u. per unit. Choose the best combination of resources. <table><tr><th>Option</th><th>L</th><th>K</th></tr><tr><td>A</td><td>11</td><td>2</td></tr><tr><td>B</td><td>4</td><td>6</td></tr><tr><td>C</td><td>8</td><td>6</td></tr><tr><td>D</td><td>8</td><td>4</td></tr><tr><td>E</td><td>3</td><td>9</td></tr></table>	Option	L	K	A	11	2	B	4	6	C	8	6	D	8	4	E	3	9
Option	L	K																			
A	11	2																			
B	4	6																			
C	8	6																			
D	8	4																			
E	3	9																			

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№	Topics of Calculus	Skills	Problems
20	The domain of a bivariate function, partial derivatives of a bivariate function and its differentials of the first order, complete increment and complete differential of the first order, derivative in direction, the gradient of a function, differentiation of complex functions, partial derivatives and higher orders differentials, differentiation of implicit functions, extremum of the bivariate functions	The ability to analyze a situation or problem in a broad context, concerning all factors that may affect it, the ability to create logical arguments, and the ability to clearly and effectively express one's thoughts and analytical conclusions in written or oral form	Investigate the Cobb-Douglas production function $y = 0.2715L^{0.1113}C^{0.9356}$, calculating: 1) average efficiency of fixed assets; 2) marginal efficiency of fixed assets; 3) marginal rate of equivalent substitution of fixed assets by the number of employed population; 4) elasticity coefficient by fixed assets; 5) elasticity coefficient of resource substitution; 6) average efficiency of the number of employed; 7) marginal efficiency of the number of employed; 8) marginal rate of equivalent substitution of the number of employed by fixed assets; 9) elasticity coefficient by the number of employed; 10) elasticity coefficient of resource substitution. Conclude the economic analysis of the function you constructed
21	Partial derivatives of a bivariate function and its differentials of the first order, partial derivatives and higher orders differentials, differentiation of implicit functions, extremum of the bivariate functions	The ability to create logical arguments, develop a consistent proof, and exclude unfounded assumptions	The production function is determined as the Cobb-Douglas one. To increase output by 5%, it is necessary to grow funds by 10% or the number of employees by 15%. In 2006, one worker produced products worth 2000 c.u. per month, and there were 1000 employees in total. Fixed assets were estimated at 4 million c.u. Write down the production function, the value of the average assets return and average labor productivity, and the output elasticity by labor and funds
22	Partial derivatives of a bivariate function and its differentials of the first order, partial derivatives and higher orders differentials, differentiation of implicit functions, extremum of the bivariate functions	The ability to create logical arguments, the ability to gather enough information for a reasoned choice and draw conclusions	The production function is determined as the Cobb-Douglas one. To increase output by 23%, it is necessary to grow funds by 46% or the number of employees by 69%. In 2016, one employee produced goods for 3000 c. u. per the month, and there were 125 employees in total. Fixed assets are estimated at 5 million c. u. Determine the production function y , the value of the average assets return and average labor productivity, and the elasticity of output for labor $E_L(y)$ and for funds $E_K(y)$.

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№	Topics of Calculus	Skills	Problems
23	Partial derivatives of a bivariate function and its differentials of the first order, partial derivatives and higher orders differentials, differentiation of implicit functions	The ability to analyze a situation or issue in a broad context, concerning all factors that may affect it, the ability to create logical arguments	A certain production can be described by applying the Cobb-Douglas function. It is known that each employee produces goods worth 100,000 c. u. per month. The total number of employees is 1,000 people. Fixed assets are estimated at 64 million c. u. It is known that to increase production by 3%, it is necessary to increase either the cost of assets by 6% or the number of employees by 9%. Determine the Cobb-Douglas function for this enterprise using its elasticity coefficients
24	Partial derivatives of a bivariate function and its differentials of the first order, partial derivatives and higher orders differentials, extremum of a bivariate function, differentiation of implicit functions	The ability to clearly and effectively express one's thoughts and analytical conclusions in written or oral form	The output Q produced by a firm is determined by the Cobb-Douglas production function $Q = 25 \cdot K^{\frac{1}{3}} \cdot L^{\frac{2}{3}}$, where K is the volume of invested capital, and L is the volume of labor. Schematically construct isoquants (level lines) corresponding to the output of $Q_0 = 50$ output units. Give an economic interpretation.
25	Partial derivatives of a bivariate function and its differentials of the first order, partial derivatives and higher orders differentials, extremum of a bivariate function	The ability to create logical arguments, the ability to clearly and effectively express one's thoughts and analytical conclusions in written or oral form	To expand production, the entrepreneur allocates 150,000 c. u. It is known that if x thousand c. u. are spent on the purchase of equipment, and y thousand c. u. on the salary of new employees, then the increase in production volume will be $Q = 0.001x^{0.6}y^{0.4}$. How should the allocated funds be distributed so that the increase in production volume is maximum?

3. Results

An experiment was conducted to check the practicality of problems collected based on the production function. The basis for the experiment were students of the following specialties: 051 Economics; 072 Finance, Banking and Insurance; 073 Management; 075 Marketing; 076 Entrepreneurship, Trade and Stock Exchange Activities from the National University of 'Kyiv Mohyla Academy' and Sumy State University.

The main objectives of the experiment were: research into the learning bivariate Functions by students of economic specialties in the course of Higher Mathematics; developing and implementing the problems system that would demonstrate the application of Cobb-Douglas functions; the impact of the problems system on the economic major's students' analytical

skills, analysis of the experiment results. The control group (CG) and the experimental group (EG) were formed at the beginning of the experiment to determine the standard of students' mathematical preparation. It was testing on the topics of the section Differentiation of univariate functions. After the experiment, the students were tested again. At the beginning and end of the experiment, students in the control and experimental groups solved the same tests developed by the authors of this study.

The experiment lasted three weeks while learning bivariate functions with help the problems systematized based on the production function. 237 students participated in the experiment, of which 120 students were included in the control group and 117 students in the experimental group:

- the control group (CG) included students from the following specialties: 051 Economics; 076 Entrepreneurship, Trade and Stock Exchange Activities from Sumy State University and National University of Kyiv Mohyla Academy. Learning the section Differentiation of Bivariate Functions in these groups was carried out according to the standard methodology;
- the experimental group (EG) included students from the following specialties: 072 Finance, Banking, and Insurance; 073 Management; 075 Marketing from Sumy State University and National University of Kyiv Mohyla Academy. Learning the section's topic was with help using a developed problems system in which production functions were applied.

The control test, offered to students at the final stage of the experiment, contained three types of problems.

The first type was dedicated to the partial derivatives of a bivariate function, namely, finding the derivative in the direction, the gradient of the function, and the first-order complete differential given in the explicit form. Such types of problems test the ability to calculate partial derivatives of bivariate functions, the ability to create logical arguments, the ability to identify problems, set specific goals for their solution and find optimal ways to achieve these goals, the ability to evaluate ideas and solutions using objective criteria and avoiding biases or stereotypes (*Skill 1*).

The problems of the second type were related to the differentiation of complex functions, higher orders partial derivatives and differential of implicit functions, and extremum of bivariate functions. These types of problems were aimed at testing students' ability to work with bivariate functions, the ability to develop consistent proof and eliminate unfounded assumptions, the ability to effectively process and interpret large amounts of information, and the ability to clearly and effectively express their thoughts and analytical conclusions in written or oral form (*Skill 2*).

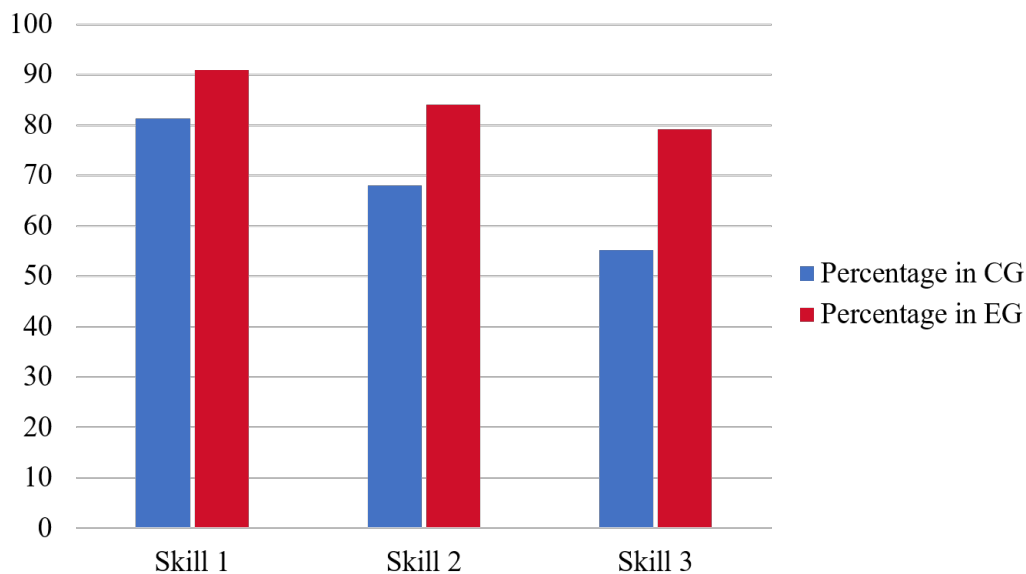
The third type of problem included applying production functions. Namely, calculating the conditional extrema of bivariate functions, finding the global extrema of a bivariate function in the domain, and finding the function's partial elasticity. These types of problems were used for testing the ability to create mathematical models, as well as the ability to adapt the results obtained by the conditions of the problem, the ability to make a specific conclusion, the ability to analyze a situation in a broad context, concerning all the factors that may affect it, the ability to build logical arguments, develop consistent proof and exclude unfounded assumptions, the ability to evaluate alternatives, collect enough information for a reasonable choice and draw conclusions, the ability to clearly and effectively express one's thoughts in written or oral form (*Skill 3*).

The percentage of correctly solved problems of the first, second, and third types, that is, the level of formation of the corresponding skill in each group, is presented in the table (table 2) and the diagram (figure 1).

The table and diagram show that the percentage of skills formation 1, 2, and 3 in the experimental group is higher than in the control group, for the first skill by 9.6%, for the

Table 2. Percentage of formation of the corresponding skill in the CG and EG.

	Skill 1	Skill 2	Skill 3
Percentage in CG	81.3	68.1	55.2
Percentage in EG	90.9	84.1	79.2

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

second skill – by 16.0%, and for the third skill – by 24.0%, which confirms the practicality of the problems system where production functions are used.

4. Discussion

Economic instability constantly accompanies as developed as developing countries, so the issue of training high-quality economic specialists is always relevant. While studying would-be economists, attention should be paid to their mathematical training because it allows students to acquire those skills and abilities that help them to master, research, and analyze various economic processes and phenomena in the future. The works of researchers Vlasenko et al. [25] and Zhelavskiy [26] confirm that mastery of mathematical modeling skills ensures the development of analytical skills of economic education students through involvement in real production processes.

It is offered that problems with Cobb-Douglas production functions be picked up while training students who major in economics. Solving such tasks contributes to developing students' analytical skills through their mathematical modeling. They study to understand the context, analyze data, make decisions, solve issues, and communicate results. Such skills allow would-be economists to train in the competencies needed in their future professional activities.

The problems' systematization on the base of the Cobb-Douglas function was carried out with the help of a combination of table and clustering methods. Individual clusters were to contribute to the development of the ability to analyze a situation or problem in a broad context, taking into account all the factors that may affect it, the formation of the ability to effectively process and interpret large amounts of information using various methods of data interpretation,

improving the ability to evaluate alternatives, collect enough information for a reasonable choice and concluding, etc.

The developed system of problems was involved while learning bivariate functions. It took three practical classes. Before presenting the tasks at the lectures, the versatility of applying the Cobb-Douglas function. There are such areas as forecasting trends in industrial development, analyzing the impact of certain climatic variables on productivity, assessing and analyzing the sustainability of the metallurgical sector, forecasting the development of farming in certain areas, etc. In addition, problem-solving was accompanied by the presentation of economic terms considered in the tasks. Working with this terminology introduces students to it and lays the ground for mastering professional disciplines. The problem-solving contributes to the immersion of its participants in real business situations keeping the proper level of motivation and interest in learning, ensuring mastery of the topic and the development of analytical skills.

5. Conclusions

Stabilization and improvement of the country's economic processes require qualified specialists. The training of high-quality economists should begin with their mathematical preparation and the development of their analytical skills. The level of such skills is ensured via mathematical modeling and training, which depends on problem-solving.

The widespread application of the Cobb-Douglas production function in many branches of the economy explains its involvement as the basis for developing the problems system. The problems' systematization can be done by combining the table method with the clustering one. The first method simplifies the problems' submission; the second ensures the filling of the cluster through the problems' correspondence to certain abilities, the development of which results in forming analytical skills of its participants.

The developed system of problems can be offered to students who majored in economic specialties while mastering Multivariate Functions. The problems' presentation should be preceded by a lecture that describes the Cobb-Douglas function application in various areas of economics and business. Economic terminology and its connection with mathematics should be presented and explained when solving problems in three practical classes. Such practice improves the students' motivation, demonstrates the connection of Mathematics with Economics, and develops students' analytical skills. The problems' systematization, which considered these conditions, ensured the study's novelty.

The system of problems can be divided into three types. The first type of problem contributes to developing skills in computing partial derivatives of Multivariate Functions, constructing logical arguments, identifying issues, setting specific goals for their solution and finding optimal ways to achieve them, and evaluating ideas, proofs, or solutions.

The problem system can be divided into three types. The first type introduced into Mathematics learning contributes to developing skills in calculating partial derivatives of Multivariate Functions, constructing logical arguments, identifying problems, setting specific goals for their solution and finding optimal ways to achieve them, and evaluating ideas, proofs, or solutions. The second type of problem can help work out higher-order derivatives, contribute to the development of consistent proofs and the exclusion of unfounded assumptions, and process and interpret significant amounts of information, clearly expressing one's thoughts and analytical conclusions in various forms. The problems of the third type for calculating the conditional extremum of Multivariate Functions, finding their largest and smallest values, make it possible to develop the skills of adapting the obtained results concerning the condition of the task, analyzing the situation or issue in a broad context, taking into account the factors that may affect it, and evaluating alternatives.

The running experiment confirmed the practicality of the implemented problem system in the experimental groups.

Future research aims to systematize the problems to introduce students to mathematical modelling while learning the first-order approximation theorem for univariate functions and their multivariate version.

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Measurement key competencies of high school students in teaching of Natural Science and Mathematics subjects

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Abstract. This article addresses the issue of finding new methodological approaches to measuring the key competencies of high school students in the learning of subjects in the natural science and mathematics educational fields within the framework of a competency-based approach. The study analyzes existing developments in methods for measuring students' competencies or their individual components, such as skills. Based on the analysis, the authors identified the urgent need for selecting and systematizing tasks that, when performed by students during the study of natural-science and mathematical disciplines, would demonstrate the level of competency development. This, in the authors' view, would not only facilitate the formation of key competencies but also provide the tools for measuring students' competencies. The authors substantiate the possibility of using students' intellectual skills as a measure of competency for assessing their competencies. The researchers aim to develop methodological techniques for using formative (supportive) and diagnostic (informational) assessments based on an analysis of existing works on evaluating students and measuring their competencies. They also aim to establish criteria for selecting cross-disciplinary tasks of varying complexity. The use of methods such as primary research, information gathering on approaches to measurement, systematization, and structural analysis of tasks, along with data processing, allowed the authors to systematize tasks in natural science and mathematical disciplines that demonstrate the interdisciplinary connections of mathematics with other subjects and provide an opportunity to assess the students' level of proficiency in mathematical modeling in the study of real-world processes. The article describes methodological recommendations for conducting formative assessment of students during the presentation of cross-disciplinary tasks. To confirm the effectiveness of measuring students' key competencies, an experiment was conducted. The results confirmed that the implementation of a system of cross-disciplinary tasks of varying complexity and the use of formative assessment allows for identifying the current level of students' competencies, relying on intellectual skills as a measure of their competencies.

1. Introduction

According to the methodological recommendations for developing components of the state standard for basic and complete general secondary education [1] based on a competency-based



approach, the secondary education system faces the task of forming, developing, and improving the competencies of students during their studies. For subject teachers, the transition to competency-based education requires improving the system of student assessment and developing strategies for measuring their key competencies. The teaching of both mathematical and natural science subjects should contribute to the formation of students' key competencies, including mathematical competence, competencies in natural sciences, engineering, technology, information and communication competence, and others.

The state standard for basic secondary education defines a set of skills that are transversal across all key competencies and should be the focus of the educational process. Therefore, teachers must have in their methodological arsenal both the means for forming competencies and effectively supporting student development, as well as tools for measuring the results obtained. Thus, there is an urgent need for finding methodological approaches to measuring the key competencies of high school students in the teaching of subjects in these educational fields.

Based on the study of the provisions of the state standard and in light of the tasks of our research on finding tools for measuring key competencies, we introduce the concept of "intellectual skills" and substantiate the possibility of considering students' intellectual skills as a measure of their competencies. Intellectual skills, as an indicator of the formation of key competencies, include: understanding information, verbally communicating thoughts, thinking critically and systematically, logically justifying positions, acting creatively, showing initiative, managing emotions constructively, assessing risks, making decisions, solving problems, and collaborating with others. The development of skills is a complex process of analytical and synthetic activity that requires certain knowledge and is based on prior experience and intellectual abilities. Mastery of intellectual skills is acquired during the learning process and ensures relative ease in acquiring creative activities and lifelong learning opportunities.

2. Literature review

The analysis of the representation of the research problem in the scientific literature was carried out in the following directions: the specifics of forming and developing a competent personality; approaches to assessing student achievements; studies on the relationship between intelligence and learning.

The issue of finding ways and approaches to the formation and development of a competent personality, as well as the specifics of such development in individual educational fields and the evaluation of the results obtained, has always been of interest to scholars.

Abylkassymov et al. [2] state that the main goals of school mathematics education are the development of students' intelligence, the formation of thinking qualities characteristic of mathematical activities, the acquisition of specific mathematical knowledge, skills, and abilities necessary for practical application, and the development of research skills. Achieving these goals necessitates the renewal of the school mathematics education system, which is called upon to ensure a harmonious combination of individual and societal interests.

Hernández García and Martínez Aznar [3] investigate digital competence as one of the eight key competencies in the Spanish curriculum. To understand the current trends related to digital competence, this research develops a systematic bibliographic review with two objectives: to identify studies that develop digital competence through didactic interventions and to gather and analyze information about their general and methodological aspects.

The issue of evaluating student achievements is one of the most discussed topics in modern didactics. Between November and December 2020, de Oliveira Araújo et al. [4] conducted a comprehensive literature review using the Scopus and Virtual Health Library databases to synthesize knowledge about assessment tools used to measure collaboration skills in IPE.

Holm and Steenholdt [5] emphasize that measuring learning outcomes is a complex issue that requires reasonable measurements for both declarative knowledge (the ability to verbalize

relevant facts or processes) and procedural knowledge (intellectual skills).

According to the study by Hu et al. [6], software assessment and competency-based education have highlighted the need to make reliable decisions regarding the high evaluation of student success based on data of different types and qualities.

García-Ruiz et al. [7] provide an updated overview of the tools used in the evaluation processes of teachers' digital competence.

Ross et al. [8] report findings from the development and pilot implementation of the competency-based achievement system.

Recently, the dominant model of control and evaluation has been criticized. As noted by Krayevska [9], this model prioritizes knowledge and skills, focusing on the selection function of assessments at the expense of development: activating and motivating students, building self-esteem, supporting self-assessment, as well as the social function, which forms relationships between the group and the individual. It encourages student passivity, lacks responsibility for the assessment result, does not provide opportunities for group collaboration and mutual understanding, and also limits the opportunities for developing activity, independence, responsibility, interpersonal skills, integrity, initiative, and teamwork. So, how should we assess in a way that helps students learn?

This is where the principles and foundations of formative assessment can be useful. This method is being implemented in domestic education as part of the New Ukrainian School concept. Formative assessment is aimed not only at assessing knowledge but also at supporting the learning process, helping students understand their strengths and weaknesses and guiding them toward improvement.

As noted by Chetvertinska [10], formative assessment is the process of identifying at what stage of learning students are, what they need to do next, and how they should best do it.

According to Sterna [11], formative assessment is frequent interactive evaluation of a student's progress and understanding of the material, allowing teachers to determine how the student should continue learning and how best to teach them. Formative assessment involves gathering information by both the teacher and the student during the learning process, which allows for recognizing how learning is progressing so that the teacher can adjust future teaching, while the student receives feedback that helps them learn.

Sterna [12], based on his own experience, describes formative assessment not just as a method used in school that consists of implementing individual elements (such as familiarizing students with lesson goals, determining success criteria, working with feedback, asking key questions, questioning techniques, peer assessment, self-assessment, collaborating with parents), but as a support system for students in learning – a strategy of a holistic approach. The goal of formative assessment is not only to evaluate the student's work, but this is just one of its elements.

In the study by Tlushchak-Deliovska and Chyzhevskaya [13], which presents a review of available Polish and English literature, formative assessment is defined as assessment that supports learning. It is one of the elements of the culture of self-regulated and autonomous learning. The student occupies a central position in the educational process, and the main idea of learning is the pursuit of forming and maintaining an appropriate level of their active position.

Many authors who present formative assessment in their research emphasize that these are not new, atypical, or innovative elements. As practice shows, teachers are familiar with these assessment methods, but despite being aware of their value, they do not always apply them in practice. The main reasons for this include their labor intensity, as well as the need for consistency and self-discipline.

Special attention should be given to studies on the relationship between intelligence and learning. Intellectual development occurs through learning. At the same time, learning activity is a form of manifestation and a key factor in the development and formation of an intellectual personality.

Jan Strelau, in his study “On Human Intelligence” [14], emphasizes, “Daily observation already convinces us that we are not equal in terms of intellectual abilities. The presence of these differences, in particular, leads to the fact that we are reluctant to assess our intellectual capabilities. Access to secondary school, and even more so to higher education, as well as performing certain social and professional functions, requires, in particular, an appropriate level of reasoning and understanding abilities, i.e., intelligence” [14].

“Daily observation shows that people differ in the speed and quality of problem-solving (life, professional, situational, etc.). Among individuals with the same education, some are able to grasp knowledge or perform a mental task that is too difficult for others. Generally, we agree that a person who cannot solve tasks that others handle easily is considered less intelligent” [14].

Problem-solving activity involves engaging various cognitive processes, such as understanding, reasoning, drawing conclusions, abstract thinking, and identification. Psychologists who equate intelligence with problem-solving focus, therefore, on cognitive processes rather than on stable intellectual traits of the individual. Thus, they are more likely to talk about intellectual behavior than intelligence itself. Intelligence is a theoretical construct related to relatively stable internal conditions of the person that determine the effectiveness of actions requiring typical human cognitive processes. Spearman [15] also closely associated the concept of intelligence with the ability to learn. Since the empirical material based on which the author constructed the concept of intelligence (factor *g*) came from students’ academic achievements in various subjects, intelligence manifests itself in learning tasks that require engaging cognitive processes such as inference and reasoning, but does not manifest itself in simple forms of learning. Jensen [16], analyzing the relationship between intelligence, measured by IQ, and learning ability, emphasizes that this relationship becomes particularly evident when the tasks subject to learning meet certain conditions: 1) the need for conscious effort, i.e., engaging willpower; 2) clearly defined structure of the task, meaning that learning complex tasks occurs after learning simpler ones; 3) the material being studied is substantive; 4) the material has an appropriate level of complexity and difficulty; 5) performing the task requires engaging cognitive activity; 6) the task corresponds to the individual’s age level.

Cattell [17], conducting a comprehensive study of the determinants of school achievements, certainly concluded that not only intelligence but also personality and motivation affect individual differences in school achievements. At the same time, he demonstrated that the interaction of these factors – intelligence, personality, and motivation – affects achievements more than any one of them separately.

Psychologists generally agree that the correlation between IQ and school achievements is about 0.50, and the variations observed here mainly depend on two factors: the method of measuring school achievements and the age of the subjects. Regarding the first factor, it turns out that the correlation between intelligence and school achievements is lower when these achievements are measured by academic results expressed in school grades. The correlation increases when the measure of school achievements is the score on a school achievement test.

Modern education primarily involves the development of students’ creative abilities based on the knowledge and skills they have acquired. The development of real intellectual powers in students is possible if they are taught to transfer the acquired knowledge to new situations, to see problems, and to find alternative ways to solve them.

In the context of improving the system of modern national education, the proclaimed ideas are reflected in the theory of competence-based education, aimed at forming an intellectually developed personality capable of independent thinking and decision-making. This allows us to characterize the competence-based approach to learning as a factor in the development of a person, particularly their intellectual skills, and at the same time requires the school to change its priorities, create a new image, develop the ability to form a new type of thinking, a new understanding of a person’s place in society, and to nurture an independent competent personality

capable of logical thinking, making decisions, and taking responsibility for them.

Based on the analysis of existing developments regarding the problem of assessing students and measuring their competencies, the aim of this study is to justify the criteria for selecting interdisciplinary tasks of varying complexity levels and also to develop methodological techniques for using formative (supportive) and diagnostic (informational) assessments of high school students' intellectual abilities as indicators of the level of their key competencies.

3. Methods

Following the views of scholars who believe that most students are subjected to intentional development of cognitive abilities, in this study, we assume that intellectual ability can be an indicator of the level of formation of key competencies if the intellectual ability is structured, and the components of this structure and their indicators become a guide for the teacher of those skills that form the key competencies in students (table 1).

The level to which skill indicators are demonstrated through activity is assessed using a point-based system:

- 0 – skill is not formed;
- 2 – skill is insufficiently formed;
- 4 – skill is sufficiently formed for academic activity in the study of the school curriculum at this stage of learning;
- 6 – skill is sufficiently formed for creative activity in learning.

The assessment of how well the indicators identified in the study have been formed is carried out during the research using various methods. The choice of these methods is determined by the specific content of the subject, the level of generalization, and the age characteristics of the students. Various methods and tools are used, such as oral individual and group questioning, observation, portfolio analysis, checking written assignments, observing the performance of practical tasks, and analyzing the execution of tasks using information technology.

These indicators and the levels of their formation allow us to assess the presence or absence of intellectual skills as a measure for evaluating key competencies. Therefore, structuring intellectual skills in terms of content and levels of formation of their components is a necessary and important task in the process of skill development.

The use of methods such as preliminary research and gathering information on measurement approaches, systematization, and structural analysis of tasks, data processing has allowed the authors of the article to systematize tasks from natural-mathematical disciplines, which demonstrate interdisciplinary links between mathematics and other subjects and provide an opportunity to determine the level of students' mastery of mathematical modeling in the study of real-world processes.

In justifying the criteria for selecting interdisciplinary tasks of different levels of complexity, it should be noted that the formation of intellectual skills is determined by the content of the tasks to which they are directed. The content of the tasks is determined by the objective world through human needs, interests, and existing knowledge. As a person becomes aware of the situation, clarifies the conditions within it, the situation transforms into a problem that motivates the search for ways to understand the unknown by revealing its connection to the known, given in the problem's conditions.

Many psychological studies (Cifarelli [18], Jaušovec and Jaušovec [19], Kostyuk et al. [20]) have been conducted on the process of solving various types of mental tasks. This process occurs as a complex analytical-synthetic activity of the subject, during which the conditions of the task and the requirements it places on the individual are correlated. The final goal is divided into a series of partial goals, with the results of achieving each previous goal becoming the means to achieve the next. There is a mental transformation of the situation with the results obtained,

Table 1. Structure of intellectual ability.

Components of intellectual ability	Indicators of skills that are revealed in activity
To understand information	The ability to emotionally, intellectually, and aesthetically perceive and comprehend what is read. The ability to identify hidden and obvious information, express assumptions, argue the reliability of arguments, and support conclusions with facts and quotations from the text. The ability to express ideas related to the understanding of the text after analyzing it and selecting counterarguments.
To express one's own thoughts verbally	The ability to express one's own opinion both orally and in writing, taking into account the purpose and participants of the communication, and choosing the appropriate communication strategies for this.
To think critically and systematically	the ability to identify characteristic features of phenomena, events, and ideas, and their interconnections. The ability to consider opposing views and counterarguments, distinguish between facts and their interpretations; the ability to recognize attempts to manipulate data by using various resources and methods to assess the quality of evidence, reliability of sources, and authenticity of information.
To justify one's position logically	The ability to express sequential, consistent, and reasoned arguments in the form of judgments and conclusions, reflecting one's own attitude towards events, phenomena, and processes.
To act creatively	The abilities to creative thinking, generation of new ideas, ethical use of others' ideas and their refinement, application of one's knowledge to create new objects, ideas, and the ability to test new ideas.
To take initiative	The abilities to active search for and proposing solutions to problems, active participation in various activities and initiating them, and aspiration for leadership, ability to take responsibility.
To manage emotions	The ability to recognize one's own emotions and the emotional state of others, to perceive emotions without judgment, to respond adequately to conflict situations, to understand how emotions can help and hinder one's activities, to adjust oneself to the search for inner balance, constructive communication, concentration of attention, and productive activities.
To consider the risks	The ability to distinguish between acceptable and unacceptable risks, considering significant factors.
To make decisions	The ability to choose problem-solving methods based on understanding the causes and circumstances that lead to their occurrence; The ability to achieve set goals with forecasting and taking into account possible risks and consequences.
To solve problems	The ability to analyze problematic situations, formulate problems, hypothesize, practically test them and justify, gather necessary data from reliable sources, present and argue solutions.

and the task is reformulated. The same task changes for the subject as they move forward in acquiring the necessary information for its solution through mental interaction with objects reflected in images and concepts.

The sequence of solving partial tasks into which the complex task is broken down is determined by the subject's overall plan, their internal action plan. If the task belongs to a category known to the subject, they find a rational way to solve it. However, if the task is new and problematic, and the solution path is unknown to the subject, they must resort to searching, hypothesizing, making guesses, and using different action strategies. Moreover, there are tasks that can be solved in several ways, and the subject can choose those that seem the most economical and effective.

Tasks vary in complexity and difficulty. Their complexity is determined by the objective conditions reflected in the content, the quality and quantity of the elements of problem situations, and the relationships between them. Difficulty is determined by the requirements that the task places on the subject and the available data they have to solve it (knowledge, skills, abilities). In the process of working on a task, certain elements of the subject's previous experience are selectively activated and brought into play to help with the work. However, if the previous experience does not correspond to the conditions of the task, it hinders its solution [21].

The study by Kostyuk et al. [20] and the conclusions formulated provide grounds for asserting that tasks play an important role in the development of students' thinking. However, the effectiveness of forming certain personal qualities depends on the extent to which the content of the task and the nature of the task system correspond to the essence of the phenomenon being formed. Therefore, when considering the task approach as one of the means of forming intellectual skills, we adhere to the point of view of those researchers [20] who view the educational task as a specific form of organizing the content of the educational material, allowing students to master knowledge and skills, as well as develop personal qualities.

Furthermore, the effectiveness of the process of forming intellectual skills will be enhanced if the tasks considered have an interdisciplinary nature and are presented to students in the form of a system. In teaching methodology, the composition of a task system is an important but not always easy task, which continuously attracts the attention of researchers.

A didactic system of tasks should meet the following requirements:

- cover the main types of available aspects of this science and related ones for students;
- cover important educationally significant methods of science, embodied in general problem-solving methods;
- account for tasks of varying complexity and different levels of cognitive activity, optimal for different groups of students
- account for didactic requirements regarding the structure, content, and repetition of tasks.

A task system created in accordance with the identified requirements, in our opinion, will contribute to the formation of intellectual skills. Intellectual skills have a general subject nature, meaning they are independent of the content of the academic discipline in which they are acquired. Moreover, the involvement of interdisciplinary connections between academic disciplines demonstrates, first, the generalization of intellectual skills and their universality in mastering the curriculum; second, the implementation of interdisciplinary connections in the process of forming skills contributes to the acquisition of creative skills: transferring learned ways of activity to new conditions, recognizing new problems in familiar situations, combining known ways of activity in new ways, and so on.

Clarifying the nature, structure, and stages of the formation of intellectual skills allowed us to develop a scheme for selecting and using tasks of an interdisciplinary nature of varying levels of complexity in the learning process. The basis of the scheme is the model of interdisciplinary connections developed by a group of authors under the guidance of Knorr [22], with some

clarifications related to the objectives of our research. The scheme (figure 1) reflects the interdisciplinary links of natural sciences in terms of forming intellectual skills in students.

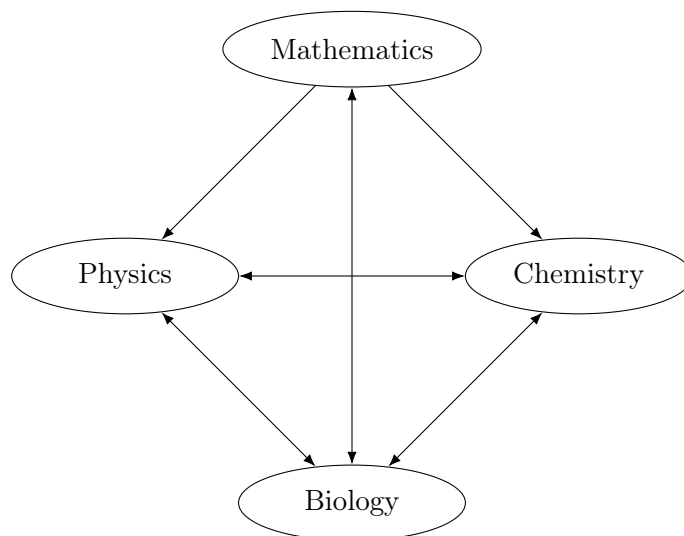


Figure 1. Scheme of intersubject relationships.

The diagram presents two-way links between the subjects of physics-chemistry, chemistry-biology, and biology-physics. Additionally, the plane of “chemistry-biology-physics” allows for, for example, using the opportunities of physics in the study of chemical-biological processes, or vice versa. The one-way link between mathematics and the mentioned subjects symbolizes the use of mathematical methods and techniques for calculations, analysis, and solving problems to acquire knowledge and skills in natural science classes.

Let’s provide examples of interdisciplinary tasks of varying levels of complexity. Physics problems that require knowledge of geometry from the 10th-11th grades’ curriculum.

Task 1. In the vertices of the base of a regular quadrilateral pyramid, there are charges. Find the electric field strength at the apex of the pyramid.

Task 2. A regular octahedron made of wire is connected in an electrical circuit at two opposite vertices, *A* and *B*. Find its total resistance, knowing that the resistance of each edge is 1 Ohm.

Task 3. The lock chamber of a canal is 300 m long, 30 m wide, and 8 m high. To fill the chamber, water is supplied through two galleries of square cross-section with sides of 4.5 m, at a speed of 2.5 m/s. How long will it take to fill the chamber?

Task 4. The surface area of a sphere made of metal with a coefficient of volumetric expansion α at 0°C was S_0 . By how much will the surface area of the sphere increase if it is heated to a temperature t_0 ?

In the above-mentioned task 1, the interconnections between knowledge in geometry (vector addition operations) and physics (electric field intensity) are applied, deepened, and expanded. Task 2 demonstrates to students how the property of symmetry in the plane of an octahedron is used in physics when calculating the resistance of conductors connected in an octahedral shape. Task 3 links the formulas for the volume of a parallelepiped to the determination of fluid velocity and material density. Task 4 strengthens students’ understanding of the use of the formula for the volume of a sphere in physics tasks related to the expansion of solids.

Chemistry problems where the optimal solution involves the mathematical concept of “average value” given that the tasks consider concepts such as “relative atomic mass of an element” and “molar mass of a gas mixture”:

Task 5. Determine the relative atomic mass of boron if it is known that the molar fraction of nuclide ^{11}B in natural boron is 19.6%, and the molar fraction of nuclide ^{10}B is 80.4%.

Task 6. Determine the relative density with respect to hydrogen of a gas mixture consisting of carbon monoxide (CO) with a volume fraction of 20% (0.2) and carbon dioxide (CO_2) with a volume fraction of 80% (0.8).

Task 7. The mass fraction of carbon in a mixture of two neighboring homologs of alkanes is 82.68%. Determine the formulas of the homologs and calculate their mass fractions in the mixture.

Biology problems that involve the use of mathematical tools:

Task 8. What area of the sea is required to feed a seagull (mass is 1 kg, dry matter – 40%) in a food chain: phytoplankton – fish – seagull? the productivity of phytoplankton is 500 g/m^2 of dry mass.

Task 9. A hare can become prey to a wolf with a probability of 0.05, a fox with a probability of 0.4, a steppe eagle with a probability of 0.1. What is the probability that the hare will survive and reproduce?

Task 10. During the summer in natural biotopes of region Z, the population size of blood-sucking insects was recorded. Within a single generation, the population size for each age group was: eggs laid $N_1 = 10000$, young larvae $N_2 = 5,000$, medium-aged larvae $N_3 = 1000$, older larvae $N_4 = 500$, pupae $N_5 = 300$, imago (adults) $N_6 = 150$. Calculate the survival coefficients for the transition from each age group to the next and the overall survival coefficient for the population. How can the differences in survival coefficients among the age groups be explained?

Since not only the content of learning but also the effective guidance of the student in this process should contribute to the formation and development of their competencies, the following methodological recommendations will explore what meaningful supportive learning and assessment of students should look.

Meaningful and supportive assessment:

- should emphasize the development of individual skills and understanding of the material, rather than just evaluating the final result;
- should include various forms of assessment, such as projects, classroom work, interviews, and practical tasks, to highlight the diversity of students' abilities;
- should provide constructive feedback that focuses on progress and offers specific areas for improvement;
- should be transparent and understandable for students, clearly defining goals and success criteria;
- should create a collaborative rather than competitive atmosphere;
- can motivate students to learn more effectively;
- should take into account individual learning styles to provide students with multiple paths to success and encourage independent thinking.

Table 2 shows the characteristics of the assessment environment.

Summing up the role of formative assessment in the process of monitoring the dynamics of competency development, it should be noted that we cannot avoid evaluation, which is understood as checking progress and determining the level of current development. Therefore, the key element is a good and fair approach to students. Honest and friendly evaluation is an extremely important component in supporting students' development. Teachers can pay attention to factors that may help create such an assessment environment.

Assessment in school should be a by-product of the learning process, and only such an approach makes sense. Therefore, we should not focus on grading. Let us try to organize the learning environment in such a way that the process runs smoothly and effectively.

Table 2. Characteristics of the assessment environment.

Description	Form of activity
Individual approach	Adapting assessment to the abilities and needs of each student.
Variety of assessment forms	Written assignments, team projects, oral presentations, and practical tasks allow for the assessment of various student skills.
Open communication	Providing students with feedback on their effectiveness, as well as specific advice on how they can improve.
Development of critical thinking skills	Encouraging to analyze, synthesize information, and express their own thoughts.
Assessment of progress, not just results	Recognizing and acknowledging efforts during the learning process.
Equality of opportunities	Ensuring that all students have equal opportunities to succeed.
Support for diverse learning styles	Providing various learning materials to give each student the opportunity to effectively absorb knowledge according to their own learning style.
Creating a culture of collaboration	Assessment not only of individual achievements but also of the ability to work in a group and support others.
Transparency of assessment criteria	Establishing clear assessment criteria and discussing them with students.
Emphasizing the value of the learning process	Ensuring that the value lies in the learning process itself, not just the final outcomes.

4. Results

The experimental learning of solving interdisciplinary tasks of varying complexity covered students from 11th experimental classes and was conducted during the general review period of natural science subjects in the second semester of the 11th grade, as well as during the elective course “Fundamentals of Cognition in Learning” when studying the third section (table 3).

A full description of the elective course “Basics of Cognition in Learning”, in which the conditions for effectively forming key competencies of high school students were tested through the introduction of tasks of varying complexity in the natural science and mathematics subjects, is provided in [23].

The goal of the experimental learning was as follows: based on the knowledge acquired by students and their own subjective experience, to reinforce the skills gained in previous stages of learning through their active use while solving interdisciplinary tasks of varying complexity. The students who participated in the experimental learning were divided into two groups: the first group – classes with in-depth study of physics and mathematics; the second group – classes with in-depth study of chemistry and biology.

Table 3. Excerpt from the syllabus of the elective course “Fundamentals of Cognition in Learning”.

№	Topic of the lesson	Hours	Type of the lesson
1	Carrying out cognitive operations of analysis and synthesis while performing interdisciplinary tasks in natural science subjects.	2	Seminar
2	Comparison of the subjects of natural science disciplines and the use of the cognitive operation of comparison during the problem-solving of natural science tasks.	2	Practicum
3	the role of generalization during the completion of interdisciplinary tasks of natural science content.	2	Practicum
4	Application of knowledge and skills transfer techniques in the process of studying mathematics, physics, chemistry, and biology.	2	Lecture
5	Generalization of knowledge from natural sciences using an integrated approach.	2	Lecture
6	Summary lesson. Final assessment.	2	Group lesson

When establishing interdisciplinary connections according to the previously described scheme (figure 1), the study of chemistry in physics and mathematics-oriented classes was organized according to certain directions, which included both physical and mathematical components. The physical component involved the use of physical laws and theories to explain chemical material, establishing relationships between physical and chemical research methods, applying physical quantities, and discovering functional interdependencies between them, as well as solving chemical problems based on physics knowledge. In turn, the mathematical component involved using mathematical methods to substantiate chemical laws and theories, applying the method of mathematical proofs, using chemical theorems and their proofs, illustrating chemical regularities with graphs, studying the geometry of molecules and its influence on the properties of substances, and solving chemical problems using mathematical equations, systems of equations, and graphs.

Using a similar scheme, the study of biology in physics and mathematics-oriented classes was also relevant. In this case, it was useful to offer students tasks in which physical laws explain biological processes, etc. Here are some examples of questions for students:

- Through what phenomenon do oxygen molecules move from the respiratory organs to the blood vessels?
- How can knowledge of the Kinetic Molecular Theory (KMT) be applied to explain the mechanism of nutrient absorption by plants from the soil solution?
- What are the physical foundations of the absorption of nutrients through the walls of the intestine into the blood?
- How much water can be heated from 37°C to boiling, using all the heat necessary for the evaporation of sweat lost by a person after a day of strenuous physical labor (10 l)? the latent heat of vaporization is $24.36 \cdot 10^6$ J/kg.
- Why does photosynthesis occur only during the day, although infrared radiation also falls on plant leaves at night?

- Why do high-energy quanta cause mutations?
- Why can't we see infrared radiation?

Upon reflection at the end of this stage, students had the opportunity to critically analyze the changes that occurred, thereby becoming aware of the interdisciplinary nature of their intellectual skills.

The forms of conducting integrated review lessons, primarily in the form of educational modules, contributed to the development of students' ability to use their own acquired experience and independently perform cognitive tasks such as planning, control, and correction.

The integrated review according to the scheme involved the following steps:

1. Review and systematization of the main theoretical provisions and leading ideas of science within the scope of the topic under study.
2. Application of the theoretical provision to practical activity or related disciplines.
3. Determining the importance of the studied provision for further theoretical development within the studied and related disciplines
4. Outlining a set of problems that can be solved based on the given theoretical provision

In both the first and second groups, integrated review occurred during physics, chemistry, and biology lessons. During this process, opportunities for mathematical modeling in biological, chemical, and physical research were identified, justified, and used. At the same time, an analysis was conducted on the role of mathematical tools in natural science research. Formative assessment of students was carried out according to the provided methodological recommendations.

While organizing learning using the integrated scheme, students were given the opportunity to understand the interdisciplinary nature of their intellectual skills, such as logically handling learning material. The content of the tasks proposed to the students contributed to the development of skills like transferring acquired methods to new conditions (e.g., a known mathematical (physical) problem is transferred to a different field of knowledge or activity, and a problem arises on how to apply it); seeing a new problem in a familiar situation (when familiar natural processes are influenced by some external factors, a problem arises that needs to be solved); and combining known methods in a new way (applying knowledge from different disciplines to solve a complex problem).

For clarity on the dynamics of intellectual skill acquisition in the experimental and control classes during the formative experiment, we present the data in percentages of the total number of students at the end of the experiment (table 4) and a histogram of the distribution of intellectual skill acquisition levels in experimental and control groups (figure 2).

Table 4. Results of the formative experiment.

Level	Beginning of the experiment			End of the experiment		
	EG ₁	EG ₂	CG	EG ₁	EG ₂	CG
High	7.7	7.9	8.25	21.1	19.9	9.5
Sufficient	6.7	6.9	7.0	65.1	64.4	14.6
Intermediate	41.5	41.4	41.2	13.8	15.7	46.3
Low	22.8	22.5	22.3	0	0	28.1
Zero	21.3	20.9	20.9	0	0	1.5

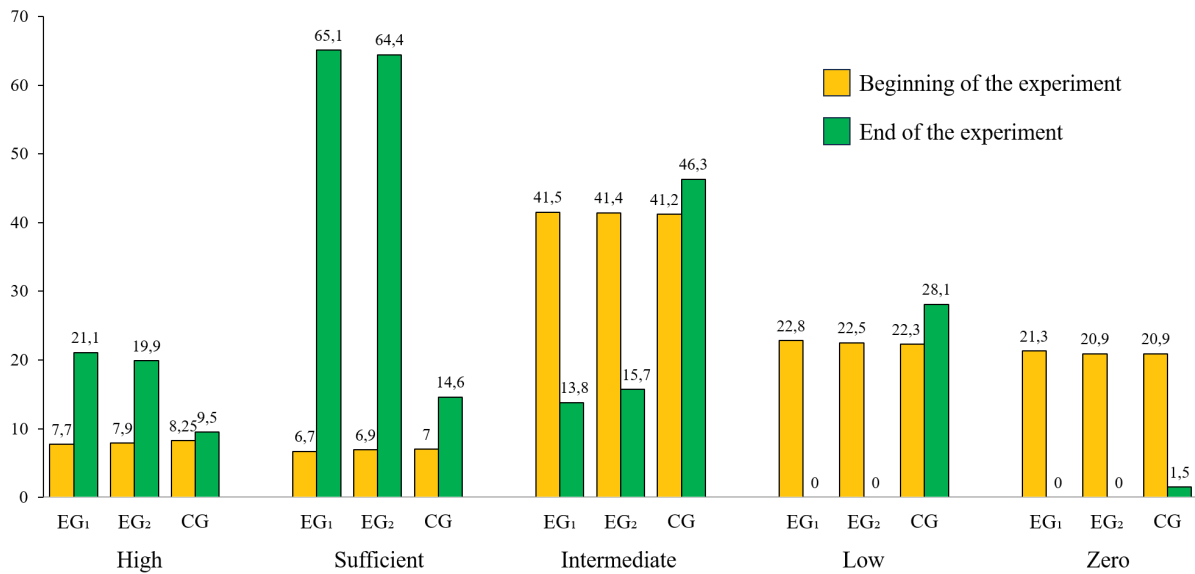


Figure 2. Histogram of the distribution of levels of intellectual skill proficiency among students in experimental and control groups.

The experiment, conducted to assess the level of students' intellectual skills, involved the use of valid methodologies and coefficients: the degree of readiness for learning aimed at developing intellectual skills was studied through surveys; the diagnosis of knowledge about cognitive operations and the ability to use mental techniques was carried out based on the results of control works in natural science subjects (EG₁ – control work in physics and mathematics, EG₂ – control work in chemistry and biology, CG – control work in mathematics and chemistry); the ability to perform cognitive actions was determined using tests.

The assessment of the results was carried out in points:

- high level – from 10 to 12 points;
- sufficient level – from 7 to 9 points;
- intermediate level – from 4 to 6 points;
- low level – from 2 to 3 points;
- zero level – from 0 to 1 point.

A more reliable evaluation of the qualitative growth of intellectual skills in the experimental class students at the final stage of the experiment, relative to their initial developmental level, as well as the development of intellectual skills in control class students, was obtained using mathematical statistics. To track the dynamics of the formation of logical culture among high school students, we used the average indicator (EI), calculated by the following formula:

$$EI = \frac{a + 2b + 3c + 4d + 5e}{100}. \quad (1)$$

where a , b , c , d , e are the percentage expressions of the number of students in each respective zero, low, intermediate, sufficient, and high levels of proficiency in intellectual skills.

The effectiveness of the experimental research was verified using the effectiveness coefficient (EC):

$$EC = \frac{AI_{EG}}{EI_{CG}}, \quad (2)$$

where EG is the result for the experimental group and CG is the result for the control group (table 5).

Table 5. Assessment of the qualitative growth in students' intellectual skills.

Groups	Average indicator	Effectiveness coefficient
EG ₁	$\frac{1 \cdot 0 + 2 \cdot 0 + 3 \cdot 7 + 4 \cdot 35 + 5 \cdot 11}{100} = 2.16$	$\frac{2.16}{1.61} = 1.34$
EG ₂	$\frac{1 \cdot 0 + 2 \cdot 0 + 3 \cdot 9 + 4 \cdot 34 + 5 \cdot 10}{100} = 2.13$	$\frac{2.13}{1.61} = 1.32$
CG	$\frac{1 \cdot 1 + 2 \cdot 14 + 3 \cdot 25 + 4 \cdot 8 + 5 \cdot 5}{100} = 1.61$	

5. Discussion

It should be noted that educational and cognitive activity is a socially significant and leading activity in the social life of a school student, accompanied by an internal psychological process of mastering learning information. Proper organization of cognition, communication, and work is a key condition for the successful functioning of the educational process aimed at comprehensive development. The findings of Kostyuk [21], which reveal the dialectical relationship between learning and mental development and how each creates the prerequisites for the successful course of the other, reinforced our opinion about the close connection between learning and students' intellectual development.

The idea of developing intellectual skills in high school students in the teaching of mathematics and natural science subjects is confirmed by the statements of scientists, which indicate that mastering cognitive operations cannot be separated from the learning process. For example, the peculiarities of high school students' thinking, highlighted by Rohaeti et al. [24], vividly illustrate the need for systematic consideration of tasks with research elements. Abylkassymov et al. [2] emphasize the potential of problem-search tasks in mathematics as a way of developing research skills in students in updated content situations.

The structure of intellectual skill development is supported by Abylkassymov et al. [2] research, which highlighted the main blocks of research skills in students and developed problem-search tasks in algebra and geometry for these blocks, along with a methodology for developing these skills.

To measure the level of student competence, Fiksl et al. [25] propose the development of appropriate tools. This confirmed the following opinion of the authors of the article. The relevance of developing interdisciplinary tasks in teaching this topic at each level is primarily due to the fact that such tasks contribute to the formation of mathematical competence as a key competency.

In developing the requirements for the system of interdisciplinary tasks of varying difficulty, the authors relied on research by scholars in the field of mathematics teaching methodology. In particular, the conclusions of Bronkhorst et al. [26] were taken into account, which emphasize that the system of tasks must adhere to the principle of gradually increasing difficulty; consider methodological conditions and the need for individualization.

Teaching mathematical modeling should occur during the study of each subject in the natural sciences cycle. This idea is supported by Little [27], who investigates the connection between mathematics and science and looks for ways to prevent middle school students from viewing mathematics as irrelevant and questioning its usefulness.

This point of view is also supported by deCotret and Vincent [28], who explore the integration of disciplinary knowledge. Arpin [29] advocates for the realization of interdisciplinary connections

benefiting both the educational needs of specific academic profiles and mathematics itself. This approach is supported by Rivard [30] research on establishing various forms of relationships between disciplines.

In matters related to the development of methodological techniques for formative (supportive) assessment, the authors find support in the research of Hu et al. [6], Ross et al. [8], Szwed [31]. Specifically, the principles of fair, reasonable, and transparent decision-making in assessment, proposed by Hu et al. [6], confirmed our view on the necessity of using formative assessment to obtain fairer and more reliable decisions to aid learning. This view is also supported by the work of Ross et al. [8], who note that the theoretical foundation of a competency-based achievement system (CBAS) is assessment for learning. In this structure, assessment becomes part of the learning process, acting as periodic checks on learning. Feedback provided to the student clearly outlines their strengths and weaknesses. Szwed [31] stresses the importance of focusing on working with educational goals, developing constructive feedback, and refining communication with students, as well as orienting assessment towards learning.

6. Conclusions

In the research, the authors raise the issue of assessing students and measuring their competencies, proposing the assumption that intellectual skills may be an indicator of the level of development of key competencies in high school students. The authors identify the components of intellectual skills, as well as the indicators of skills that are revealed in activity. The level of development of these indicators is assessed in points, which allows determining the presence or absence of intellectual skills as a measure of key competencies.

Tasks play an important role in the development of students' thinking; however, the effectiveness of forming specific personal qualities depends on how the content of the task and the nature of the system of tasks correspond to the essence of the phenomenon being formed. The authors of this article succeed in systematizing tasks from natural science and mathematical disciplines, which demonstrate interdisciplinary links between mathematics and other subjects and allow identifying the level of students' mastery of mathematical modeling in real-world process research. Regarding the selection and systematization of interdisciplinary tasks of varying difficulty, the researchers propose using interdisciplinary connections of natural science subjects in the context of developing intellectual skills in students. The researchers recommend systematizing tasks according to bilateral interdisciplinary links such as physics-chemistry, chemistry-biology, and biology-physics. The one-way connection between mathematics and the aforementioned disciplines symbolizes the use of mathematical methods for studying natural processes, thereby forming mathematical competence as a key one.

Understanding the nature of intellectual skills, their structure, and stages of formation allowed the researchers to justify criteria for selecting interdisciplinary tasks of varying difficulty levels, develop a scheme for selecting and using these tasks in the learning process.

According to the authors' recommendations, formative assessment of students' achievements during the formation and measurement of competencies should align with the characteristics of the assessment environment. The authors highlight a group of characteristics and teacher activities to ensure their integration into the learning process.

The positive results of implementing a system of interdisciplinary tasks of varying difficulty levels in teaching natural science subjects are evidenced by the experimental teaching conducted. The results demonstrated the effectiveness of offering students a system of interdisciplinary tasks at different levels of complexity to help them understand the interdisciplinary nature of intellectual skills, see new problems in familiar situations, and combine known ways of activity in new ones. Furthermore, measuring the level of intellectual skills formation allows conclusions to be drawn about the level of students' competencies.

The authors view the further development of the methodology of formative assessment for

high school students during the acquisition of subject-specific competencies in mathematics and natural science education as the prospect of future research.

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Modern aspects of forming the motivation of learning activities of bachelors of mathematics in the process of studying professional disciplines

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Abstract. The study explores the formation of motivation among mathematics undergraduates in the context of professional training. A combination of theoretical methods (analysis, synthesis, comparison, generalization), modeling, and empirical methods (surveys), as well as statistical analysis, was utilized. The research analyzes contemporary approaches to motivation and psychological-pedagogical concepts of its structure, identifying key aspects relevant to developing learning motivation in mathematics students. The study involved 86 undergraduate students (aged 18–22, 57% female) from the Faculty of Mathematics, Physics, and Computer Science at Vinnytsia Mykhailo Kotsiubynskyi State Pedagogical University. Surveys were conducted using the “Motives for choosing a profession” methodology and A. Rean’s “Motivation for Success and Fear of Failure” questionnaire. Ethical standards, including APA guidelines, were strictly adhered to. The findings highlight two motivational types: positive motivation, characterized by a drive for success and self-confidence, and negative motivation, marked by anxiety and avoidance of failure. The use of modeling enabled the creation of a comprehensive approach to assess motivation through criteria, indicators, and levels of motivational development. This research contributes to understanding how motivational factors influence the academic success of mathematics students and offers practical tools for enhancing their professional training.

1. Introduction

The formation of sustainable motivation for academic activities is a pressing challenge in modern pedagogy [1]. This issue is particularly critical for educators in higher education institutions working with future professionals. Students’ level of motivation impacts not only their academic success but also their future professional fulfillment.

Currently, the topic of motivation, both academic and general, is extensively studied. Internal and external connections between different types of motivation have been established, and numerous successful classifications of motivation types and kinds have been proposed. The structure of motivation comprises three groups of motivating factors: needs and instincts that determine individual orientation; emotions, feelings, and experiences; and attitudes that regulate the dynamics of student behavior. Some researchers argue that influencing the professional motivational sphere of students involves restructuring it, increasing the proportion of intrinsic



over extrinsic motivations through academic motives. These motives drive students to learn and include attitudes “(e.g., psychological readiness for cognitive activities), cognitive needs, and interests that shape their focus, persistence, and other volitional qualities” [2].

Vasiuk et al. [3] state that “motivation is a system of complementary motives formed and expressed in activities”. Researchers have explored the specific characteristics of academic motivation among higher education students, identifying leading motives. This study refuted the hypothesis that acquiring knowledge and developing skills are the primary drivers of students’ academic motivation, with obtaining a diploma being less significant. The research revealed that success is not always a determining factor in academic motivation, indicating that a student’s character and personal qualities significantly influence their motivation to learn.

Klibanivska [4] highlights that optimizing a student’s potential requires directing their focus toward academic activities, which serve as both a motive and a goal. The study demonstrated that dominant motivations evolve throughout the years of study. Students’ priorities shift from external to intrinsic motivations, with a growing emphasis on educational and professional competitiveness based on deep knowledge acquisition. The research also found that the primary academic motivation for first-year students is professional, personal prestige for second-year students, a combination of both for third-year students, and the addition of pragmatic motives for fourth-year students. Professional and educational motives remain priorities across all years. Additionally, changes in academic activities from the third year onward reflect an increasing emphasis on cognitive achievement and competitiveness.

Despite differences in findings between studies by Vasiuk et al. [3] and Klibanivska [4], both emphasize that academic success influences student motivation [3] and that success strongly impacts professional and cognitive motives [4].

According to Schunk [5] and Valenzuela-Peñuñuri et al. [6], “academic motivation is referred to as the disposition that is related to academic functioning, learning, and success, as well as the effort made by students and persistence to achieve the goals they set for themselves”.

Research on autonomous motivation has been conducted by Azila-Gbette et al. [7], Jeno et al. [8], and Mouratidis et al. [9] define autonomous motivation as “behaviors students endorse out of their own will; behaviors carried out because they find them interesting, fun, or challenging (intrinsic motivation); because they consider such behaviors part of their own identity (integrated regulation); or because they view them as meaningful and personally important (identified regulation)”.

On the other hand, Duta et al. [10] highlights that without communication, teaching and learning processes cannot occur. Communication skills and work motivation significantly influence teaching activities, as the instructor’s communication style can affect student engagement and attitudes, creating an appropriate learning atmosphere.

Innovative monitoring of academic habits and motivation in learning mathematics at the undergraduate level is discussed in Szilágyi et al. [11].

Simanjuntak et al. [12] aimed to explore mathematics learning motivation in the context of blended learning based on gender. They found no significant difference in motivation levels between male and female students using blended learning models.

Self-regulation in mathematics learning during professional training is examined in Berger’s research [13]. The author employs a dual-methodological approach: (1) path models to explore links between variables related to motivation and metacognition; and (2) a person-centered analysis (latent profile analysis) to identify student groups with varying competency goal configurations.

Lim et al. [14] analyze academic motivation for mathematics in adaptive learning systems using Rasch analysis. Their study aims to validate the Academic Motivation Toward Mathematics Scale (AMTMS) based on self-determination theory, applied to secondary education levels (grades 11 and 12) in Asia.

Mayerhofer et al. [15] investigated aspects related to motivational beliefs and associated factors that are crucial for fostering a positive attitude toward lifelong learning, particularly in the context of university education. In many German universities, successfully completing introductory courses is a prerequisite for further degree progression. As a result, prospective undergraduate mathematics students face high levels of pressure and often engage in externally motivated activities [16]. Liebendörfer emphasized the significant role of the institutional environment in shaping the motivation of mathematics students.

Moreover, students often attempt to adapt learning strategies to meet course requirements [17], such as aligning their time management with mandatory course demands and seeking help from peers to complete assignments. In summary, the challenges of transitioning from secondary to higher education are multifaceted [18]. Heublein et al. [18] identified nine categories of reasons why undergraduate students in Austria drop out of their chosen programs across all fields of study. The most critical reasons include academic performance difficulties, lack of learning motivation, and career orientation issues (e.g., a desire for practical work). Code et al. [19] examined the development of motivational indicators among first-year mathematics students and found that all indicators declined during their first year at university.

The crucial role of motivational factors in academic activities is reflected in the principle of motivational support in the learning process, which addresses contradictions between the existing and required levels of motivation; between personal and societal needs, goals, and interests; and between students' motivational attitudes and their functional capabilities. Addressing these contradictions during professional training necessitates a shared understanding among educators of motivational goals and strategies for achieving them. The authors believe that achievement motivation and self-affirmation motivation are essential for forming professional motivation among mathematics undergraduates. Academic success depends on the interplay of individual abilities, achievement motivation, and situational factors (e.g., favorable conditions). Achievement motivation encompasses both personal traits and situational factors such as perceived value, likelihood of success, and task difficulty [20].

The main aim of the study is to propose approaches and tools aimed at increasing the motivation of mathematics bachelor's students while studying professional subjects, as well as to verify the results of the educational study using statistical analysis.

The main objectives are to describe the theoretical foundations and analytical approaches to developing learning motivation among mathematics bachelor's students in the process of studying professional disciplines; to define the criteria, indicators, and levels of development of the motivational-value component of professional training; and to apply Kolb's learning cycle, interest-based motivation, and achievement value motivation in solving applied problems aimed at modeling real-world objects and phenomena.

2. Methods

The study employed various methods: theoretical (analysis, synthesis, comparison, and generalization), modeling, and empirical methods (surveys), along with statistical techniques for processing research data and calculating statistical indicators.

An analysis of scientific research and resources dedicated to contemporary approaches to studying motivation and motives was conducted. This included an examination of psychological and pedagogical concepts of motivation, its types, and its structure in the context of training mathematics undergraduates. This analysis facilitated the identification of relevant aspects of fostering learning motivation among mathematics undergraduates during the study of professional disciplines.

The analysis of materials published in philosophical, psychological-pedagogical, and methodological periodicals formed the basis for defining the conceptual framework, systematizing and summarizing existing experiences, justifying theoretical propositions, developing and

implementing original ideas, and performing statistical analyses within the selected topic.

The use of modeling methods enabled the creation of a comprehensive approach to assessing student motivation by determining criteria, indicators, and levels of formation of the motivational-value component in the professional training of mathematics undergraduates.

To explore the relationship between internal and external motivation and personal qualities, we conducted two tests among mathematics undergraduates across all four years of study. These tests included the methodology “Motives for Choosing a Profession” and A. Rean’s “Motivation for Success and Fear of Failure” questionnaire [21].

The study was conducted among students of the Faculty of Mathematics, Physics, and Computer Science at Vinnytsia Mykhailo Kotsiubynskyi State Pedagogical University. The final sample included $N = 86$ bachelor’s students from the first to fourth years (approximately 18–22 years old, 57% female).

The survey was conducted with the utmost respect for participants’ privacy and confidentiality, adhering to ethical standards and the guidelines of the American Psychological Association (APA) as well as the Ethical Code of the Ukrainian Researcher. Faculty administration was informed about the study. Parental consent was not required, as all students were over 18 at the time of the survey.

Students from the first to fourth years were invited to complete a Google Form survey. The form contained tables with response options based on the “Motives for choosing a profession” methodology and A. Rean’s “Motivation for Success and Fear of Failure” questionnaire [21].

Motivation for success relates to positive motivation. With this type of motivation, students begin tasks with the aim of achieving something constructive and positive. Their academic activity is driven by a hope for success and a need to achieve it. Such students are typically confident, responsible, proactive, and active. They are characterized by persistence, goal orientation, and determination in achieving their objectives.

Motivation for failure, on the other hand, is a type of negative motivation. In this case, a student’s activity is driven by the need to avoid failure, criticism, punishment, or setbacks. This motivation is rooted in avoidance and negative expectations. When beginning a task, a person motivated by fear of failure anticipates possible setbacks and focuses on ways to avoid them rather than on achieving success. Individuals with this type of motivation tend to exhibit heightened anxiety and low self-confidence. They often avoid taking on significant responsibilities and may experience near-panic states when faced with highly demanding tasks. In such situations, their situational anxiety becomes extremely pronounced, although this can coexist with a relatively responsible attitude toward their work.

3. Motivation in mathematics learning: theoretical framework and analytical approaches

In this study, motivation is studied using the “expectancy-value” theory [22], which suggests that students’ perceptions of studying mathematics are influenced by four components [22, 23]:

1. Intrinsic value – the enjoyment or intrinsic interest in mathematics.
2. Attainment value – the importance of achieving success in mathematics, reflecting personal identity and self-expression.
3. Utility value – the usefulness of mathematics for achieving future goals, such as career aspirations.
4. Cost – the perceived effort, stress, or negative consequences associated with studying mathematics.

Intrinsic value pertains to the enjoyment or curiosity students experience when engaging with mathematics. This component is closely linked to intrinsic motivation, where students participate in learning activities because they find them enjoyable or fulfilling.

Example: A student who enjoys solving puzzles may find satisfaction in solving complex problems in algebra, geometry, mathematical analysis, etc. because they find them interesting or intellectually stimulating.

Applications in education: teachers can develop students' interest by incorporating fun and interactive activities such as mathematical games, real-world problem-solving scenarios, or creative projects such as creating geometric artwork, 3D modelling and 3D printing of bodies, surfaces, etc., and modelling real-world processes using numerical methods or differential equations.

Attainment value reflects how important success in mathematics is to students, as it aligns with their identity or sense of self. This value is particularly significant for students who view mathematics as a core part of their identity or as a means of expressing their abilities. Such students are more likely to invest effort in self-education.

Example: a mathematics major may strive to excel in mathematics to support this aspect of their identity, they may take pride in being considered the best in the group or in being able to explain to other students how to solve a difficult problem, design their own problem, or write an interesting research project. Students who view mathematics as a way of self-expression are more likely to invest in self-education, more likely to seek out additional materials, practice, and improve their competencies on their own.

Applications in education: Teachers can support the value of achievement by recognising and rewarding students' mathematics achievements, encouraging them to set personal goals, and viewing mathematics as a skill that reflects their intellectual growth and self-discipline.

Utility value refers to the perceived practicality or relevance of mathematics in achieving personal aspirations, career goals, or everyday life tasks. Students who understand how mathematics connects to their future are more likely to remain motivated, even if they do not fully enjoy it at the moment.

Example: a student who aspires to become an engineer may not enjoy maths, but is studying hard because he knows that maths is essential for his career goals. Similarly, another student may find maths essential for managing finances or understanding data in everyday life. Future teachers who are aware of how mathematics helps in teaching and career development are more likely to show interest in their chosen profession.

Applications in education: Teachers can emphasise real-world applications of mathematics, such as its role in different professions, technology, or even everyday tasks such as budgeting and shopping. Guest lectures from professionals or project-based learning (e.g. creating a budget for a simulated business) can emphasise the practical value.

Cost refers to the potential drawbacks or sacrifices students associate with studying mathematics. These may include stress related to completing tasks, the effort required, or the fear of failure. A high perceived cost can demotivate students, even if they recognize the importance and utility of the subject.

For example, a student may feel overwhelmed by mathematics assignments, which currently take up too much of their time, leaving them less time for leisure or other favourite activities. Another student may avoid active participation in practical classes for fear of making a mistake and embarrassing themselves in front of their classmates.

Applications in education: Reducing perceived cost involves creating a supportive classroom environment where mistakes are seen as learning opportunities. Teachers can also break down complex tasks into simple steps, provide resources for additional support, and emphasise effort rather than innate ability to build students' confidence [24].

These factors influence students' decisions to engage with mathematics and their persistence levels. Previous research highlights the importance of these elements in skill development: while interest, perceived importance, and utility enhance positive outcomes, cost-related factors can hinder progress [25, 26].

Values are subjective, as individuals assign different levels of importance to the same tasks. For instance, success in mathematics may hold significance for some students but not others [23]. Attainment value emphasizes the importance of succeeding in tasks integral to one's self-concept, such as excelling in mathematics through personal identity. Intrinsic value reflects the satisfaction derived from the task itself, encouraging deeper engagement and sustained effort. Utility value highlights how a task aligns with future goals, such as meeting academic requirements for a degree. While utility value may resemble extrinsic motivation, it often reflects meaningful personal goals, linking it to both achievement value and self-concept [22].

The **Situational Expectancy-Value Theory** (SEVT) extends traditional expectancy-value theory by focusing on how task value and success expectations shift across contexts. It emphasizes the dynamic and context-dependent nature of motivation, especially during critical educational decision-making moments [23]. SEVT suggests that students are more motivated by tasks aligned with their self-concept (achievement value) or future aspirations (utility value).

The **person-centered approach** is often associated with the holistic-interactionist paradigm introduced by Magnusson [27] and further developed by Bergman [28]. This paradigm views the individual as an active agent within the "person-environment" system. Its key principles suggest that there is order and structure both in intra-individual consistency and change, as well as in inter-individual differences in consistency and change. This order and structure can be described as patterns of involved factors, and some patterns occur more frequently, while others occur less frequently than theoretically expected [29].

Using the person-centered approach, students can be categorized into motivational profiles based on combinations of factors (e.g., interest, achievement, utility value, and cost). This approach accounts for the complexity of individual differences in motivation, allowing researchers to examine how specific profiles are related to academic outcomes and engagement [25, 26].

Identifying common motivational profiles enables tailored recommendations for educational practices. For instance, interventions can focus on enhancing the intrinsic value of mathematics for students who perceive it as overly demanding or misaligned with their goals.

This approach not only identifies individual differences but also bridges theoretical gaps by offering practical insights into the connection between motivation and learning [30].

Components of expectancy-value theory provide criteria, indicators, and levels to assess motivational and value-based aspects of professional preparation for mathematics undergraduates, offering a comprehensive approach to evaluating motivation in mathematics learning (table 1).

Analyzing the conclusions of numerous researchers alongside our long-term observations of the psychological characteristics of the academic and cognitive development of mathematics undergraduates, we can identify three stages in the evolution of their motivations: learning motives (Stage I), a combination of learning motives and future professional motives (Stage II), and professional motives (Stage III).

Stage I (1st–3rd semesters): characterized by relatively high levels of learning motivation.

Stage II (4th–6th semesters): focuses on the development of the motivational sphere by combining learning and future professional motives, forming the foundation for professional motivation.

Stage III (7th–8th semesters of undergraduate studies and 1st–3rd semesters of master's studies): marked by greater awareness and integration of various forms of learning motives. During this period, students study professional and practical disciplines, making it the critical phase for the formation of professional motivation.

According to Podoliak and Yurchenko [2], learning motives are not only prerequisites for successful professional education but also its outcomes. Motives are formed through activity, which the teacher organizes, while students' attitudes toward this activity develop within it.

Notably, as motivation increases, so does the quality of students' academic activities and

Table 1. Criteria, indicators and levels of formation of the motivational and value component of professional training of bachelor of mathematics.

Indicators of maturity	Levels of formation			
	initial	average	sufficient	high
Intrinsic value (interest in learning and academic discipline)	lack of interest in the discipline and learning activities, situational interest in certain topics, fear of failure	interest in learning activities appears, all positive motives are associated only with the result, a certain tendency of motivation to fail	stable orientation of cognitive motives and interest in learning in general and mathematics in particular, a certain tendency of motivation to success	deep awareness of cognitive motives, general goal-orientedness, success-oriented
Attainment value (ability to self-education)	no ability to self-education, tendency to fulfil the minimum requirements for graduation	self-education skills are partially developed, there is no initiative in acquiring new knowledge	the desire for self-education and self-development is developed, but not sufficiently manifested	systematic and conscious self-education activities aimed at increasing key competences of the individual
Utility value (interest in the chosen profession)	lack of motivation and interest in the future profession, random choice of speciality; material, prestigious and utilitarian motives prevail	formal interest in the profession of mathematics teacher, studying is a condition for obtaining a diploma; synergistic combination of moral and aesthetic motives with material, utilitarian and aesthetic motives	conscious choice of the future profession, learning activities consciously aimed at acquiring professional competence; synergistic combination of cognitive and professional motives with moral, aesthetic, material, utilitarian and aesthetic motives	awareness of personal and social significance of the profession of mathematics teacher; synergistic combination of social and creative motives with cognitive, professional, moral, aesthetic, material, utilitarian and aesthetic motives
Cost (reflection, self-analysis)	the ability to introspect is not formed	there are skills of self-analysis, the formation of which occurs mainly under the influence of external factors	ability to carry out adequate self-assessment, ability to organise personal, educational, professional activities	awareness and understanding of the results and prospects of their own activities; ability to overcome obstacles and achieve success

achievements. Teachers must identify the optimal motivation level at which this activity is most effective. Psychologists have demonstrated that excessive motivation in some individuals can lead to heightened activity and tension, resulting in disruptions in performance and behavior. Over-intense external stimulation (e.g., threats) and high motivation levels can provoke undesirable emotional reactions such as stress and anxiety, impairing performance [20].

Experimental studies have shown that both low and excessively high levels of motivation result in reduced performance. This phenomenon is encapsulated in the Yerkes-Dodson law: as motivation intensity increases, performance quality initially improves, reaches an optimal point, and then declines [20].

4. Formation of student motivation in the cyclic model of experiential learning

Some universities in Ukraine, under the conditions of martial law, have been forced to operate in remote and blended learning formats. In such circumstances, it is crucial to sustain students' motivation to study mathematical disciplines. Frequent air raid alerts and power outages make it difficult for instructors to focus students' attention on learning materials, leading to a backlog of unresolved educational tasks and, at times, an inability to conduct classes. The acquisition of professional competencies by mathematics undergraduates under such challenging educational conditions largely depends on their motivation.

At the first and second stages of the formation of learning motives and the combination of learning and future professional motives in mathematics undergraduates, David Kolb's experiential learning cycle model [31] can be effectively employed. This model implements the expectancy-value theory of motivation by Eccles [22].

Kolb is renowned for his work on experiential learning and contributions to organizational behavior studies. His research focuses on individual and social change, learning through experience, career development, and professional education [31].

Kolb's model proposes a learning cycle consisting of four sequential stages: "Concrete Experience" – "Reflective Observation" – "Abstract Conceptualization" – "Active Experimentation". The model presents two dialectically connected processes of understanding experience (concrete experience and abstract conceptualization) and two modes of transforming experience (reflection and active experimentation).

This process integrates the following elements:

- knowledge – comprising concepts, facts, and information obtained through formal education and past experience.
- activity – the application of knowledge in real-world situations.
- reflection – analysis and synthesis of knowledge and activities to generate new insights.

Kolb emphasize that the learning cycle can start at any of the four stages and should be viewed as a continuous, sequential spiral [31].

Application in mathematics education:

1. *Abstract conceptualization*: learning begins when a student encounters a new and intriguing mathematical problem or situation, which sparks their intrinsic motivation. This stage aligns with the expectancy-value theory by Eccles [22], as it highlights the value of student interest in learning mathematics.

Theoretical lessons can incorporate simulations such as role-playing, debates, or brainstorming to encourage active discussion and idea exchange. Teachers utilize digital interactive platforms and tools to engage all students, showcasing applied problems and mathematical modeling of real-world systems or processes to stimulate cognitive motivation. Presentation tools like Canva or PowerPoint, along with mathematical visualization software such as GeoGebra or Desmos, help convey complex theoretical material. The use of

interactive resources like quizzes, competitions, or creative projects further enhances interest and engagement. For example, the Quizizz platform enables quizzes in team or individual formats, providing a leaderboard at the end to highlight top performers.

2. *Active experimentation*: at this stage, students apply fundamental mathematical knowledge to solve practical problems. They actively engage by asking themselves: “What needs to be done? How can this be solved? What steps should I take?”

Practical tasks combine motivation through interest – students derive satisfaction from solving complex problems – and achievement, as they realize their capabilities. This dual-component approach integrates theoretical knowledge with its practical application, as posited by the expectancy-value theory.

Group activities such as data collection, discussion of problem-solving methods, and idea sharing foster collaboration. For example, the “jigsaw” method allows group members to examine problems from different perspectives.

Students are encouraged to develop projects, participate in competitions, and explore creative solutions, which not only deepen their theoretical understanding but also cultivate essential practical skills for future professional environments.

3. *Concrete experience*: this stage involves analyzing data and developing theoretical frameworks to enhance understanding. Students assess the utility of their mathematical knowledge for various professions. They reflect on the significance of their prior achievements and evaluate how the acquired knowledge benefits their future careers.

Activities include independent research, group discussions, role-playing, critical thinking exercises, forecasting, modeling, and analyzing conclusions. Educators may also encourage students to prepare academic projects [32,33], scientific papers, or participate in innovative competitions.

4. *Reflective observation* involves critically assessing the experiential learning process, identifying strengths and weaknesses, and determining areas for professional growth. Students analyze alternative solutions, compare methods, and evaluate their outcomes.

Formative assessment techniques such as “know – learned – want to learn”, open-ended questions, or one-minute essays help students reflect on what they have learned, how it relates to their future profession, and how theoretical knowledge translates into practical use. Interactive tools like digital boards or structured group activities foster engagement and critical evaluation.

Maintaining motivation requires fostering both interest and achievement. Feedback tools such as messengers, social networks, and Google Classroom comments enable instructors to respond quickly to student queries and support practical tasks.

Students’ efforts are further characterized by their level of digital competence, which influences their activity, engagement, and speed of completing assignments in remote or blended formats. Proficiency in programming languages and computational tools empowers students to automate routine calculations, create algorithms, and solve complex problems, preparing them for success in modern academic and professional settings.

Kolb’s experiential learning model provides an effective framework for fostering student motivation through a balanced integration of theoretical knowledge and practical application. By encouraging reflection, active participation, and digital competency, educators can create a dynamic and engaging learning environment even in challenging conditions (figure 1).

4.1. Structure of a lesson based on Kolb’s experiential learning cycle

Starting the learning process by demonstrating an applied problem of modeling real-world objects and phenomena, the instructor implements the “practice, experiment, testing” stage of Kolb’s experiential learning cycle, simultaneously addressing value motivation through intrinsic

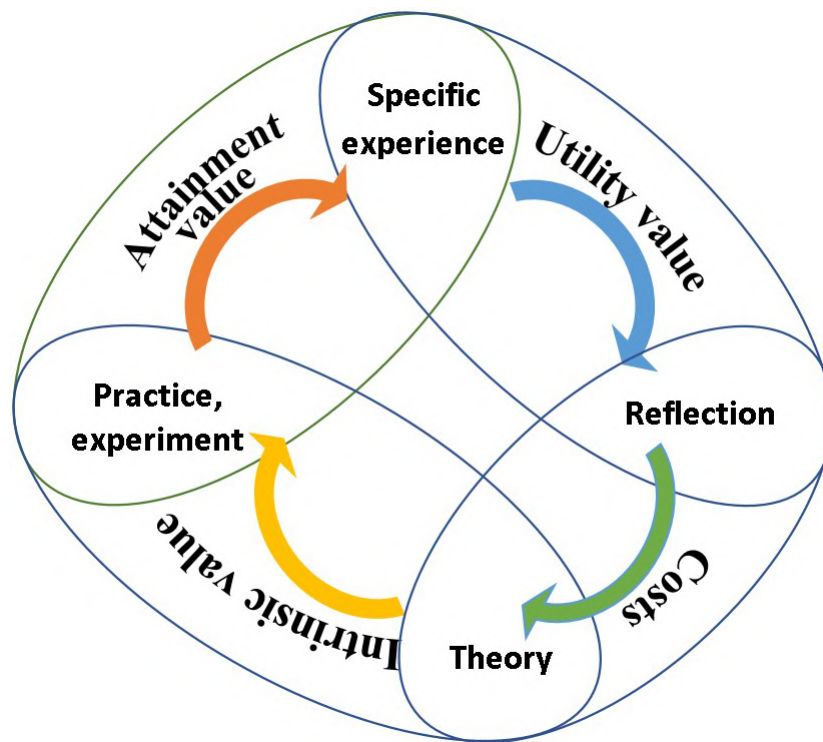


Figure 1. Motivation of students through experiential learning according to the Kolb's experiential learning cycle.

and attainment as per Eccles theory. For example, students may be tasked with determining the time it takes for a projectile fired from a cannon under specified initial conditions to hit the ground [34] (figure 2).

The instructor then demonstrates various methods for solving this problem, employing both mathematical and computational modeling approaches. Students learn to analyze a real-world physical problem by constructing its mathematical model and applying numerical methods such as the bisection method (or Bolzano method), Newton-Raphson method, false position (or regula falsi) method, secant method, combined method, and fixed-point iteration method [34].

Students gain practical experience and understand that the problem can be solved using various numerical methods, both manually and with the help of applied mathematical software. This corresponds to Kolb's "concrete experience" stage and reinforces the value of attainment and utility in Eccles theory (figure 3).

The analysis, observation, comparison, and critical evaluation of the obtained experience (results of calculations using different methods) lead to a deeper understanding of the outcomes. Students select the optimal method for solving the problem by weighing the advantages and disadvantages of each considered method. This corresponds to Kolb's "reflection and analysis" stage and the value of utility in Eccles theory (figure 4).

The final stage of the first cycle involves understanding the theoretical and fundamental principles behind applying mathematical and computational modeling methods to solve applied problems. This aligns with Kolb's "conceptualization of knowledge and theory" stage and the cost in Eccles theory (figure 5).

After completing all four stages of empirical learning according to Kolb's cycle, when the general principle is understood, the next step is to complete the second cycle in new, supplemented, more complex mathematical problems based on the specific experience gained

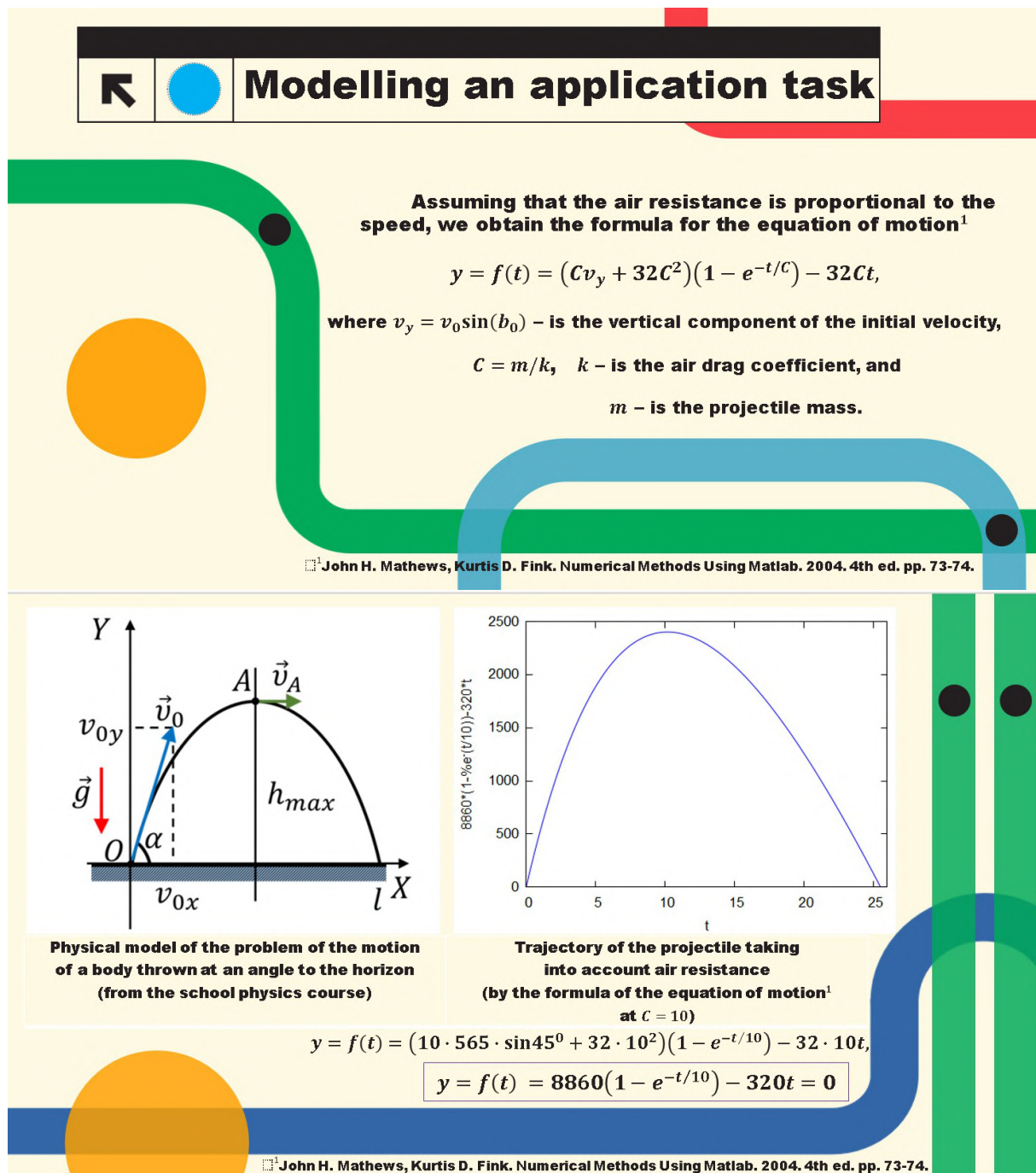


Figure 2. Information model of a real physical problem (interest value).

in the previous cycles of learning. In this way, a complex empirical spiral of learning through Kolb's cycles is built.

5. Discussion

The authors of the article offered the 1st-4th year students of the Faculty of Mathematics, Physics and Computer Science of VSPU to take a survey in Google form in the form of a table

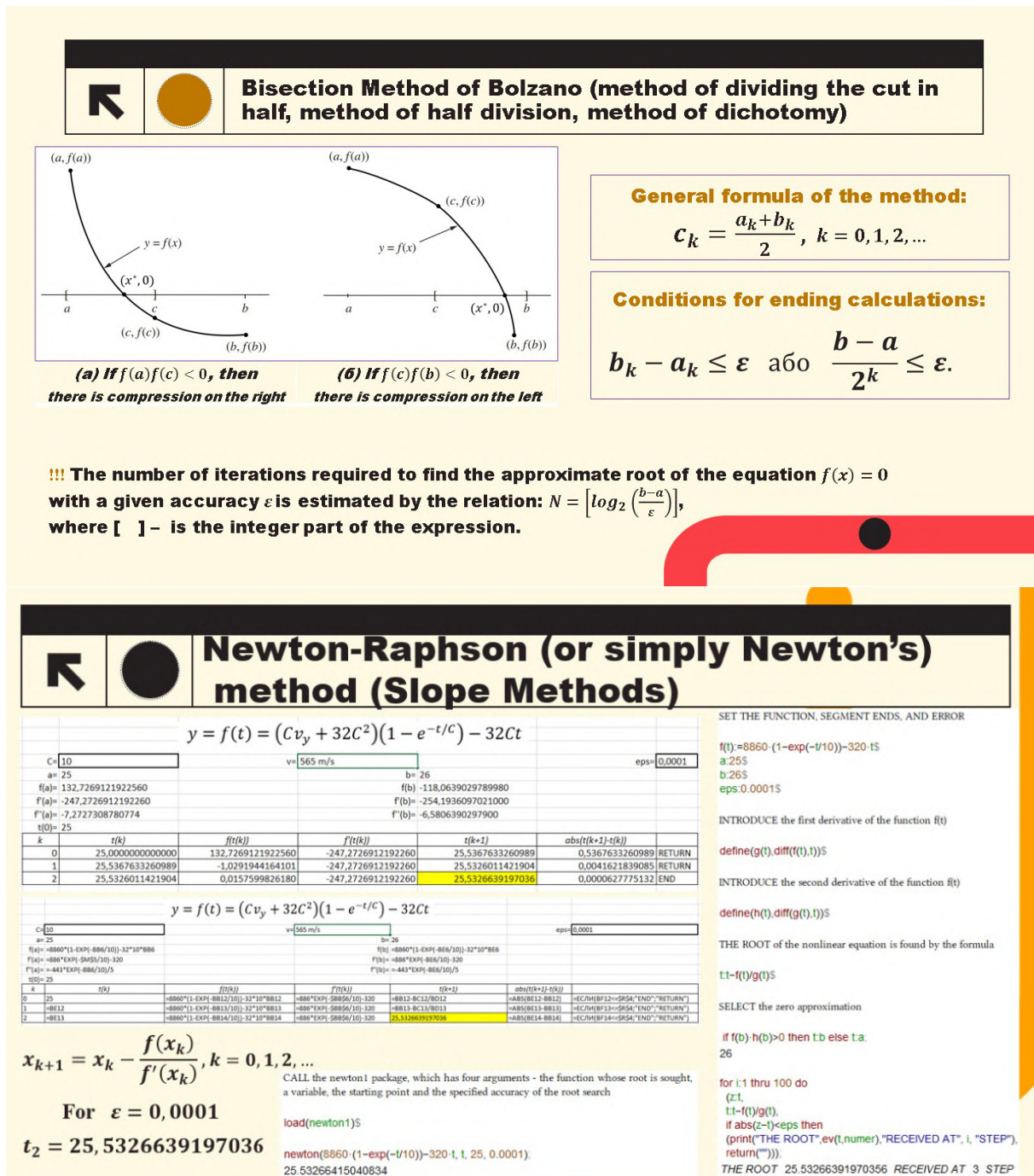


Figure 3. Fragment of mathematical and computer modelling of a problem (value of achievements).

with answer options according to the methodology “Motives for choosing a profession” and A. Rean’s questionnaire “Motivation for Success and Anxiety of Failure” [21].

To establish a statistical relationship between the motives for choosing a profession by bachelors of mathematics of 1-2 years (49 people) and bachelors of mathematics of 3-4 years (37 people), the Spearman’s rank correlation coefficient r_s was used. The ranks are not repeated,

Results for $\varepsilon = 0,0001$	
$t_{14} = 25,5326843261718$	Bisection Method of Bolzano (or Bisection Method)
$t_2 = 25,5326639197036$	Newton-Raphson (or simply Newton's) method (or Slope Methods)
$t_2 = 25,5326637265664$	False Position or Regula Falsi Method (or Chord Method)
$t_1 = 25,5326639211523$	Secant Method
$t_2 = 25,5326454018548$ $t_1 = 25,5326639226616$	Combined Method
$t_2 = 25,5326643588203$	Fixed-Point Iteration (or Method of Iterations)

FIND THE EXACT SOLUTION

CALL the newton1 package, which has four arguments - the function whose root is sought, a variable, the starting point and the specified accuracy of the root search

```
load(newton1)$
newton(8860*(1-exp(-t/10))-320*t, t, 25, 0.0001);
25.53266415040834
```

Figure 4. Practical experience: comparison of results obtained by different numerical methods (cost).

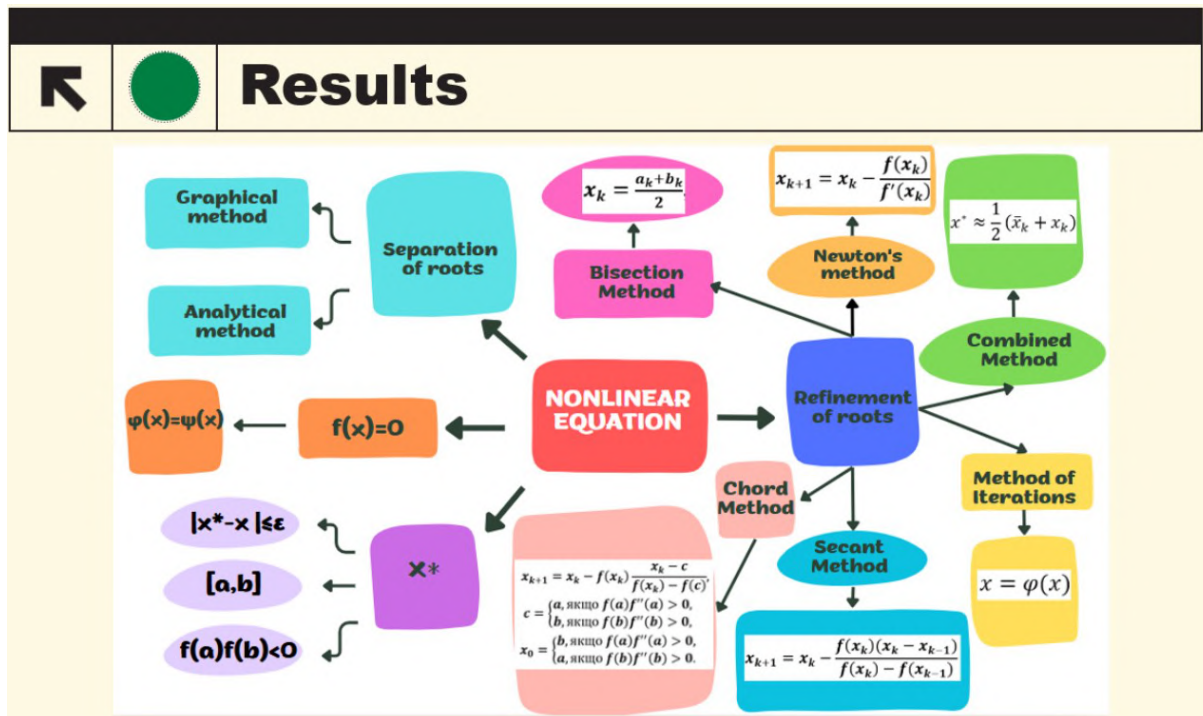


Figure 5. Theoretical foundations: summarising the material with the help of a knowledge map (usefulness).

so the empirical value of Spearman's r_s correlation coefficient will be determined by the general formula: $r_s = 1 - \frac{6 \sum d_i^2}{n(n^2-1)}$, where n is the number of features, d_i – is the difference in ranks: $d_i = R_{X_i} - R_{Y_i}$; d_i^2 is the square of the rank difference [35]. The coefficient r_s takes values in the range from -1 to $+1$.

The primary data of the results of the survey of bachelors of mathematics of 1-2 courses (X) and bachelors of mathematics of 3-4 courses (Y) by the methodology “Motives for choosing a profession” are presented in the order scale (table 2).

Table 2. Primary data and intermediate calculations based on the results of the survey of bachelors of mathematics 1-2 years (X) and bachelors of mathematics 3-4 years (Y).

№	Groups of motivations	X	Y	d_i	d_i^2
1	Social	5	5	0	0
2	Moral	4	3	1	1
3	Aesthetic	7	6	1	1
4	Cognitive	1	1	0	0
5	Creative	3	2	1	1
6	Related to the content of work in the chosen profession	6	7	-1	1
7	Material	9	9	0	0
8	Prestigious	8	8	0	0
9	Utilitarian	2	4	-2	4
		<i>Sums</i>		0	8

We set the probability level of the first kind of error and formulate the null and alternative hypotheses for $\alpha = 0.01$:

H_0 : there is no statistically significant correlation between the motives for choosing a profession by bachelors of mathematics in the 1-2 year of study (X) and bachelors of mathematics in the 3-4 year of study (Y) ($r_s = 0$);

H_1 : there is a statistically significant correlation between the motives for choosing a profession by 1-2 year mathematics bachelors (X) and 3-4 year mathematics bachelors (Y) ($r_s \neq 0$).

The empirical value of Spearman's rank correlation coefficient r_s :

$$r_s = 1 - \frac{6 \sum d_i^2}{n(n^2-1)} = 1 - \frac{6 \cdot 8}{9 \cdot (9^2-1)} = 0.93.$$

For a degree of freedom $df = n = 9$ and a given $\alpha = 0.01$, according to the table of critical values of Spearman's r_s correlation coefficient, $r_{crit} = 0.798$ [35]. Since $r_{emp} > r_{crit}$ ($0.93 > 0.798$), hypothesis H_0 is rejected. The size of the standardised effect according to Cohen's classification is large ($r_s = 0.93$). Therefore, there is a statistically significant direct correlation between the indicators of the importance of the motives for choosing a profession by bachelors of mathematics of 1-2 years (X) and bachelors of mathematics of 3-4 years (Y) (figure 6).

According to the statistics of the Spearman's r_s criterion ($r_s = 0.93$; $p > 0.01$; $n = 9$), there are no grounds for accepting the null hypothesis. The results of statistical research are debatable, so it is worth increasing its statistical power by studying the motivation of mathematics bachelors' learning activities, in particular in different educational institutions by increasing the size of respondents' samples and using various methods of organising a pedagogical experiment. The results of the survey “Motivation for Success and Anxiety of Failure” according to A. Rean's methodology are ranked and presented in table 3.

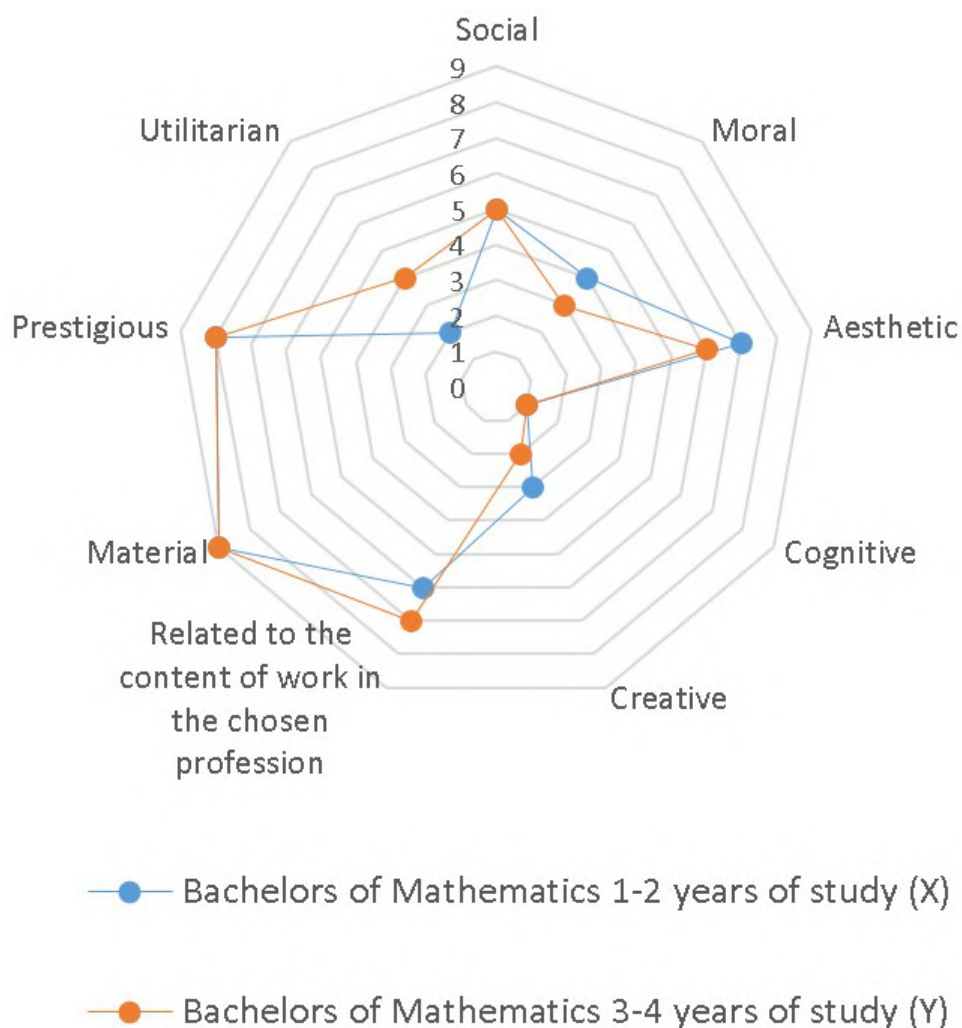


Figure 6. Groups of motives 1-9 according to the “Motives for choosing a profession” methodology (table 2) and its significance for bachelors of mathematics at Vinnytsia Mykhailo Kotsiubynskyi State Pedagogical University.

Table 3. The results of the survey of bachelors of mathematics of 1-2 courses (X) and bachelors of mathematics of 3-4 courses (Y).

№	Groups of motivations	X	Percentage of students	Y	Percentage of students
1	Motivation to anxiety	4	2.1	4	8.1
2	A certain tendency of motivation to anxiety	3	10.2	3	13.5
3	A certain tendency of motivation for success	2	36.7	2	27.0
4	Motivation to succeed (hope for success)	1	51.0	1	51.4

Modern students of the 1st-4th years of study are primarily focused on motivation to succeed or demonstrate a tendency to succeed. This may be due to the fact that the choice of profession is more often made at the stage of master's studies rather than during bachelor's studies. At

the bachelor's level of education, students mostly focus on acquiring general knowledge and skills that open up wide opportunities for future professional fulfilment. At the same time, the motivation to succeed at this stage is formed as a desire for academic excellence, which allows students to create a basis for further specialised study and career development.

6. Conclusions

The article describes the theoretical foundations and analytical approaches to developing learning motivation among mathematics bachelor's students in the process of studying professional disciplines, based on the expectancy-value theory [22, 23], which suggests that students' perception of learning mathematics is shaped by four components of task value: interest value, attainment value, utility value, and cost. The authors demonstrate that these components can be operationalized using criteria, indicators, and levels of motivation-value formation in the professional training of mathematics bachelor's students, providing a comprehensive approach to assessing motivation in mathematics education.

The study reveals that analyzing students' learning motivation helps to identify the driving factors that determine individual activity. Since success in any activity depends not only on abilities and knowledge but also on motivation, the transformation of external motives into internal ones stimulates students to higher levels of activity aimed at achieving success. It has been confirmed that applying the author's methodology throughout all stages of professional training—specifically, a lesson design based on Kolb's learning cycle and the motivation components of interest value and attainment value, which simulates stimulating situations—creates conditions for the intensive development of achievement motives. These motives later transform into professional ones, positively influencing students' satisfaction with their career choice, as well as their activity and independence in mastering elements of professional practice.

Three stages in the development of mathematics bachelor's students' motives have been identified:

1. Learning motives (Stage I).
2. Combination of learning and future professional activity motives (Stage II).
3. Professional activity motives (Stage III).

It is recommended to apply David Kolb's experiential learning model across all three stages. This model incorporates the value components of Eccles et al.'s theory, contributing to students' motivation to study mathematics. The authors have developed educational and research tasks for modeling real-world objects and phenomena.

To explore the relationships between intrinsic and extrinsic motivation as well as personal qualities, two tests were conducted among first- through fourth-year mathematics bachelor's students from the Faculty of Mathematics, Physics, and Computer Science at VSPU: "Professional motivation of students" and A. Rean's "Test-Questionnaire on Motivation for Success and Fear of Failure". Statistical analysis was performed using Spearman's rank correlation coefficient (r_s). It was proven that a statistically significant direct correlation exists between the importance of professional choice motives for first- and second-year mathematics students and those of third- and fourth-year students at VSPU. According to Cohen's classification, the standardized effect size is high.

The research results can be utilized by university instructors during mathematics courses to enhance students' motivation for learning.

Future research should focus on exploring the continuity of learning motives across secondary specialized education, pre-university, and higher mathematics education levels.

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Supporting the mathematical education of STEM students: development of an adaptive learning course for independent study

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Abstract. The article addresses the issue of the gap between the level of school mathematical training and the requirements of university for students of STEM specialities, especially in the context of current global and local challenges, such as the COVID-19 pandemic and military actions in Ukraine. Based on the analysis of the cognitive, pedagogical and psychological aspects of learning, the main difficulties faced by students are identified, particularly insufficient conceptual understanding of mathematical concepts, lack of basic procedural skills, decreased motivation and psychological discomfort. The authors substantiate the need to create additional resources to support the mathematical education of first-year university students. As one of the possible tools for solving this problem, an adaptive training course in the LMS Moodle is proposed, focused on eliminating knowledge gaps, forming a conceptual understanding of mathematical concepts and developing mathematical thinking. Particular attention is paid to integrating the STACK automated assessment system to develop adaptive tests that allow personalising learning. A description of the course structure, its methodological and technical features, and the challenges associated with implementing this approach are presented. The proposed approach can be used to support first-year students and improve the quality of mathematics education in the context of modern challenges.

1. Introduction

1.1. Problem statement and its topicality substantiation

Mathematics education is a fundamental component of STEM students' training because it forms the ability to think analytically, solve complex problems and master key professional competencies, and mathematical knowledge and skills underpin many disciplines studied at the university level.

However, the transition from school to university education is accompanied by significant difficulties for first-year students. It should be noted that the issue of the gap between school and university mathematics education is not new; it has been documented in numerous studies [1–4]. In particular, studies [2–4] confirm that a significant gap between the level of school mathematics and the university curriculum in mathematics and disciplines that include a mathematical component leads to serious difficulties, especially in the first year. Even 50% of students with high school grades do not succeed in university mathematics. Similar statistics



are provided by Vollstedt et al. [4], who note that in Germany, about half of first-year students in STEM university majors have issues mastering university disciplines that require deep basic mathematical knowledge and skills that were not formed at the school stage.

The global and local crises of recent years have only exacerbated this problem. The COVID-19 pandemic has led to a massive shift to distance learning, which has had a negative impact on the quality of both school and university education due to limited interactivity and insufficient control over the educational process [5–8]. A general decline in students' performance in mathematics has been observed in many countries, as documented by large-scale international studies such as PISA and TIMSS. This trend is also highlighted in a recent report by the Royal Society of New Zealand [9].

In addition to the consequences of COVID-19, Ukraine has an additional burden – the war [10–12]. The destruction of educational infrastructure, mass migration of the population, including schoolchildren, university students, teachers, lecturers, many of whom are still outside Ukraine [13], large-scale missile attacks and destruction of critical infrastructure, and the occupation of territories, the collaboration of some teachers with the occupation authorities, the lack of shelters suitable for full-fledged education, work and study under constant stress and air raids have become unprecedented challenges for the education system and have caused significant educational and training losses.

These losses are particularly pronounced in mathematics education, as mathematics education is most vulnerable for several reasons. **Firstly**, the regularity of learning is disrupted. Long breaks have a detrimental effect on individuals' mathematical skills, as close intra-subject connections characterise mathematics and, therefore, require constant practice. The loss of knowledge and skills in one topic negatively affects the ability to understand and learn other topics. **Secondly**, learning mathematics requires close interaction with a teacher. During wartime, offline learning becomes inaccessible for most students. Asynchronous learning is also limited and ineffective due to technical issues such as power outages, internet connectivity problems, and a lack of access to adequate resources. **Thirdly**, in crisis conditions, when participants in the educational process experience stress, their psycho-emotional state deteriorates, which significantly reduces their ability to focus on learning. Learning mathematics requires high concentration and motivation, so in such circumstances, this subject can be perceived as particularly difficult and its study a lower priority compared to the focus on subjects related to basic life skills and social aspects. **Fourthly**, due to migration, mobilisation and other consequences of Russian military aggression, Ukraine has lost many qualified teachers and lecturers. This creates a shortage of specialists, which directly affects the quality of mathematics teaching.

As a result, we have a very disappointing situation, particularly regarding the level of mathematical knowledge of school graduates. Almost 40% of Ukrainian school leavers who took the National Multisubject Test in 2024 have low levels of mathematics knowledge, nearly 47% have an average level of proficiency, and only about 13% have above-average and high levels of proficiency [14]. That is, the knowledge of most school leavers is superficial and formal, with no conceptual understanding of mathematical concepts, facts, or methods, and many have not developed mathematical thinking or understand the nature of mathematics. Due to gaps in school education, almost 87% of graduates have insufficient knowledge to study STEM-related fields in higher education successfully. This requires the creation of additional support resources to help bridge the gap between the level of school mathematics training of applicants to STEM specialities and the university requirements for their mathematical training.

1.2. Analysis of the latest research and publications

A number of studies have been analysed, and three key aspects of the gap between school and university mathematics education can be identified.

Cognitive. Students are accustomed to procedural problem-solving, which prevailed at school, face difficulties mastering abstract mathematical concepts, conceptual understanding and formal thinking [15, 16]. For example, the concept of a limit, taught intuitively at school, acquires a strict formal interpretation at university, making it difficult to understand and recognise (students often see nothing in common between the school and university interpretations of this concept) [17]. Research also shows that students do not always recognise the same mathematical concepts in different disciplines because they are interpreted from various perspectives [4].

Pedagogical. Differences in teaching approaches at school and university also significantly impact students' adaptation. The school focuses on explaining the material and solving typical problems, while the university programme emphasises independent work, theoretical study of the material, and formal proofs. This transition causes stress and disorientation for students, as they are unprepared for high academic independence [4, 18].

Clark and Lovric [19] emphasise that university mathematics is dominated by a deductive approach and is based on rigorous proofs, which are often absent from school teaching. In addition, unlike school textbooks, university textbooks do not provide adequate didactic support for learning proofs. Formal mathematical language and the use of symbols complicate the adaptation process, increasing the so-called 'shock of the new' among students.

Psychological. Students often experience decreased self-confidence, especially if they have difficulty understanding new material at the beginning of their studies. This can lead to anxiety, loss of motivation, or even dropping out [20]. For example, Greek students reported feeling afraid to ask questions of their teachers because they were scared of looking incompetent [15]. Psychological difficulties are exacerbated by the reduced personal attention students receive from teachers compared to school. Changing environments, new social contexts, and high expectations of teachers create additional pressure [21].

Various researchers have explored different strategies to address educational gaps, demonstrating varying degrees of effectiveness:

- courses focused on abstract thinking, formal logic, and mathematical proofs have shown promise [22, 23];
- delivering lectures at a slower pace and incorporating analogies, visualisations, and metaphors has significantly increased student motivation [24];
- adapting content to meet students' needs by considering their thought processes and prior experiences – especially by simplifying complex ideas without losing their core essence – has been beneficial [25, 26];
- identifying problem areas through testing and self-study of the material has contributed to improved educational outcomes [27];
- the use of the Inquiry-Based Learning (IBL) strategy, which adopts a research-oriented approach to learning and solving open-ended problems, has helped bridge knowledge gaps and enhance student motivation [28];
- development of metacognitive-oriented educational materials for independent work and its guidance in an electronic learning course [29].

Despite some local successes in addressing the gap between school and university mathematics education, a comprehensive approach is needed to consider cognitive, pedagogical, and psychological factors. We require effective mechanisms to support students early in their university studies in STEM fields. High-quality tools are essential for diagnosing and quickly aligning students' mathematical knowledge and skills with the necessary standards. Therefore, the research aims to develop an adaptive learning course that will bridge the gap between school mathematical training and the requirements of university programs.

2. Methods

We used research methods as follows. Firstly, we analysed and reviewed scientific and didactical literature to i) uncover the phenomenon of educational losses and the understanding of the gap between the level of mathematical training in schools and the requirements of universities for students in STEM fields; ii) design an adaptive learning course for independent study. Secondly, we employed empirical methods. In December 2024, we surveyed lecturers of Borys Grinchenko Kyiv Metropolitan University about the issues with the school's mathematical training of first-year students. The survey included 17 participants who teach mathematical or professionally oriented disciplines, focusing on fields that require a significant mathematical component in mathematical, technical or economic specialities. The survey was conducted anonymously, and all participants gave consent. Empirical data were used solely for both quantitative and qualitative analysis.

3. Results

3.1. Results of the survey

A survey conducted among mathematics lecturers revealed that, the overwhelming majority of respondents (12 people or 70.6%) indicated that they experienced challenges in teaching related to insufficient prior mathematical training of students, 8 people, or 47.1%, indicated that these issues were significant and greatly complicated teaching; no lecturer reported that there were no issues.

When asked about the percentage of students who successfully master mathematical subjects or subjects with a significant mathematical component, 3 people (17.6%) indicated that this percentage was less than 20 (i.e. not even every fifth), and 9 people (53.0%) believe that this figure is less than 40%. Only one respondent said that most students (more than three-quarters) successfully mastered these disciplines. These results underline the urgent need for additional support for students, in particular, to correct their level of mathematical training.

The survey revealed that a significant majority, specifically 58.8% of respondents, believe that the mathematical training of first-year students from their previous schooling is gradually declining. Additionally, 23.5% of lecturers reported a noticeable deterioration in this level of preparedness over recent years. Furthermore, 70.6% of the educators surveyed indicated that, due to students' insufficient mathematical foundation, they are compelled to lower the pace, complexity, and academic rigour of their teaching or even adjust their requirements. This underscores the seriousness of the issue and indicates the need to improve students' mathematical training at the early stages of their education, in particular by modernising teaching approaches and providing additional learning support.

3.2. Description of the adaptive learning course

We offer an adaptive learning course in the Moodle LMS "Confident Mathematical Start in STEM. Fundamentals of Algebra, Geometry and Mathematical analysis for first-year students". We are actively working on developing this course, which will be an effective tool for eliminating gaps in knowledge and skills and creating a solid foundation for further study. The proposed course is also aimed at developing skills in mathematical proof thinking, forming a conceptual understanding of mathematical concepts, facts, methods and procedures, and gradually adapting students to university education requirements. It should help to improve understanding of complex mathematical concepts, develop procedural proficiency and thus reduce anxiety among students.

An essential condition for effective mathematics teaching is students' active involvement in learning. If students do not actively participate in activities, they will not understand mathematics profoundly, and their learning ability will be significantly limited. Numerous studies [30] confirm that active learning (as opposed to passive learning) positively impacts

educational outcomes. Such strategies contribute to forming a conceptual understanding of mathematical structures, which is the basis for high-quality conceptual and procedural knowledge, the development of creative thinking, research skills, and meta-skills.

The adaptive course is focused on the use of active learning strategies and the development of a student's ability to learn independently. It will be an effective tool to overcome the possible psychological discomfort of first-year students associated with the fear of direct communication with lecturers, especially regarding gaps in their knowledge, as the work with it will be organised in LMS Moodle and will allow students to avoid direct interaction with the lecturer, working independently in a comfortable learning environment. Thanks to the adaptive training tests, students can practice and overcome their difficulties and gaps in mathematical training without fear of judgment or misunderstanding.

The list of content modules (topics) for the course is derived from an analysis of the results of NMT 2023 [31] and 2024 [32], as well as a survey of university lecturers. It also incorporates insights from a study on the expectations of university educators regarding the preliminary mathematical requirements for studying STEM disciplines. This includes a Delphi study conducted with German university lecturers focused on the first semester of mathematics courses in STEM programs [1]. The list features 14 topics from the school mathematics curriculum, including algebra, geometry, and analysis foundation, along with 2 topics designed to enhance general mathematical competencies, namely the fundamentals of mathematical logic and the general theory of equations and inequalities (figure 1).

The peculiarity of the adaptive course will be that it will not require the direct presence of the lecturer and will be worked on by the student independently, remotely, in a convenient mode. The course structure is based on the principles of flexibility and adaptability. The course content modules are relatively independent and self-sufficient and can be used by students either individually or in a particular combination, depending on the need. A student can take 'their' content module in parallel with the study of a particular discipline, filling in the gaps to successfully master that discipline. This will allow for the creation of personalised learning paths to eliminate gaps in understanding and knowledge of mathematical concepts and problem-solving skills.

The content modules have a clear structure that ensures the logic and consistency of the learning material. At the beginning of each module, some keywords help students quickly understand the main idea. This is followed by a brief overview of the content, which introduces students to the general provisions of the topic. Each module clearly outlines the learning outcomes – the knowledge and skills the student must master (figure 2).

Self-diagnostic tests at the beginning of the module and final assessments at the end are provided to determine the initial level of preparation and to assess student progress. The fundamental theoretical information is presented in text format, accompanied mainly by multimedia materials, including videos. Particular attention is paid to analysing common mistakes in understanding and interpreting certain mathematical concepts, facts, and methods. The textual format of the essential theoretical information is organised to compensate for the lecturer's direct, 'live' communication with students. This implements the principle of interactivity and creates conditions for reading the mathematical text in a research manner.

For this purpose:

- the theoretical material is divided into short content-completed blocks, and after each of them, questions (or tasks) are offered to test the understanding of the theory;
- the material is presented predominantly dialogically, imitating the student's reasoning (with questions, doubts, objections, searching for and formulating a hypothesis, etc.). Presentation language is not clerical and bookish but 'live', personified, and close to direct communication;

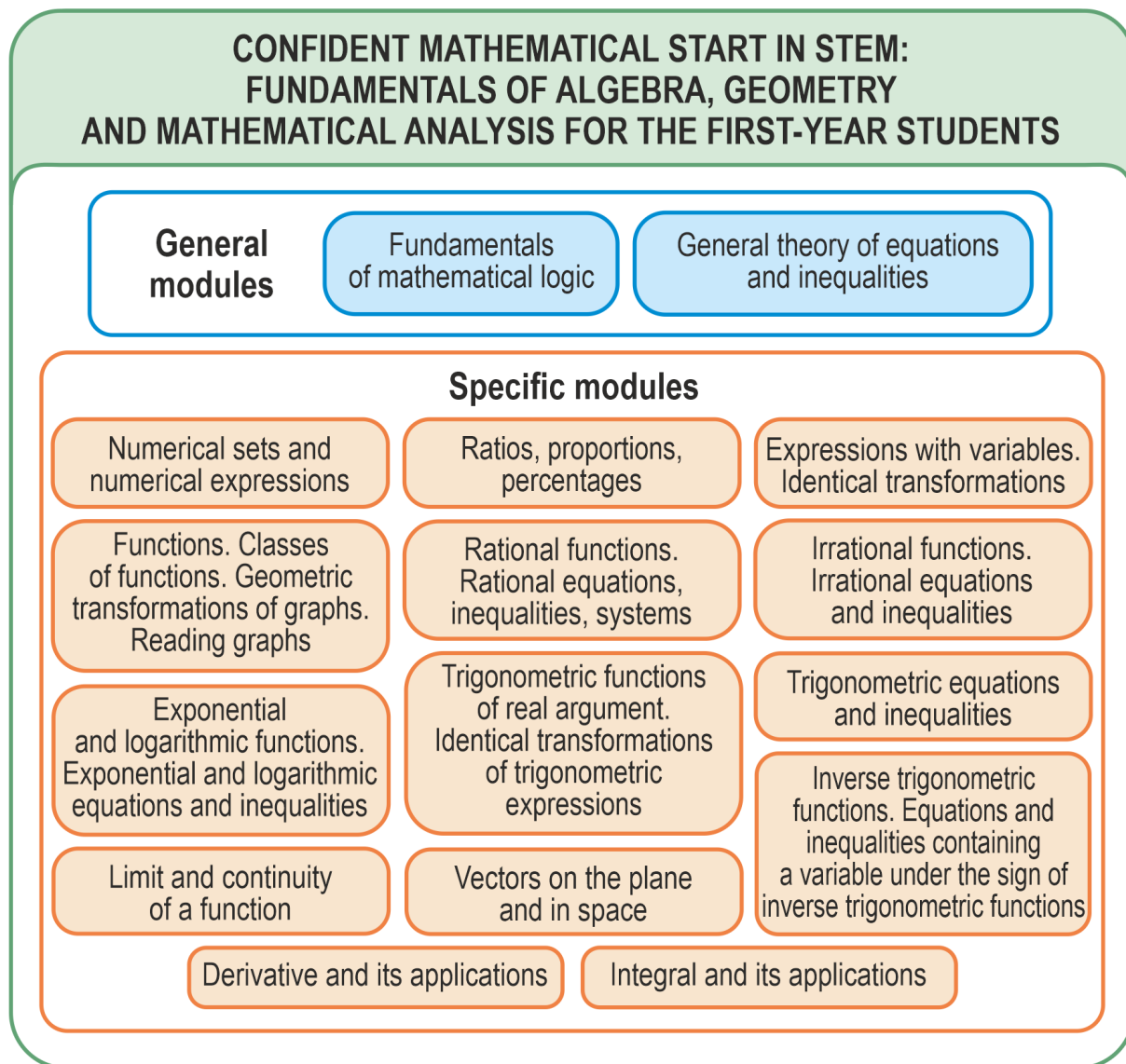


Figure 1. The list of content modules.

- the proposed test questions (tasks) are primarily open-ended, with programmed errors and adequate corrective comments on incorrect answers. The effectiveness of this approach has been confirmed [33].

The practical part of the content module includes solved examples of key tasks, emphasising typical (or possible) mistakes and training exercises. Training exercises are test tasks that are automatically verified in STACK (figure 3).

Using the STACK system for computer-based testing of test tasks allows, in particular:

- randomly generate many tasks of the same type and automatically check them, which saves the educator a lot of routine technical work;
- develop adaptive step-by-step tests when tasks (or questions) are not fixed linearly. The task of the next stage is automatically generated depending on the student's answer at the current stage;

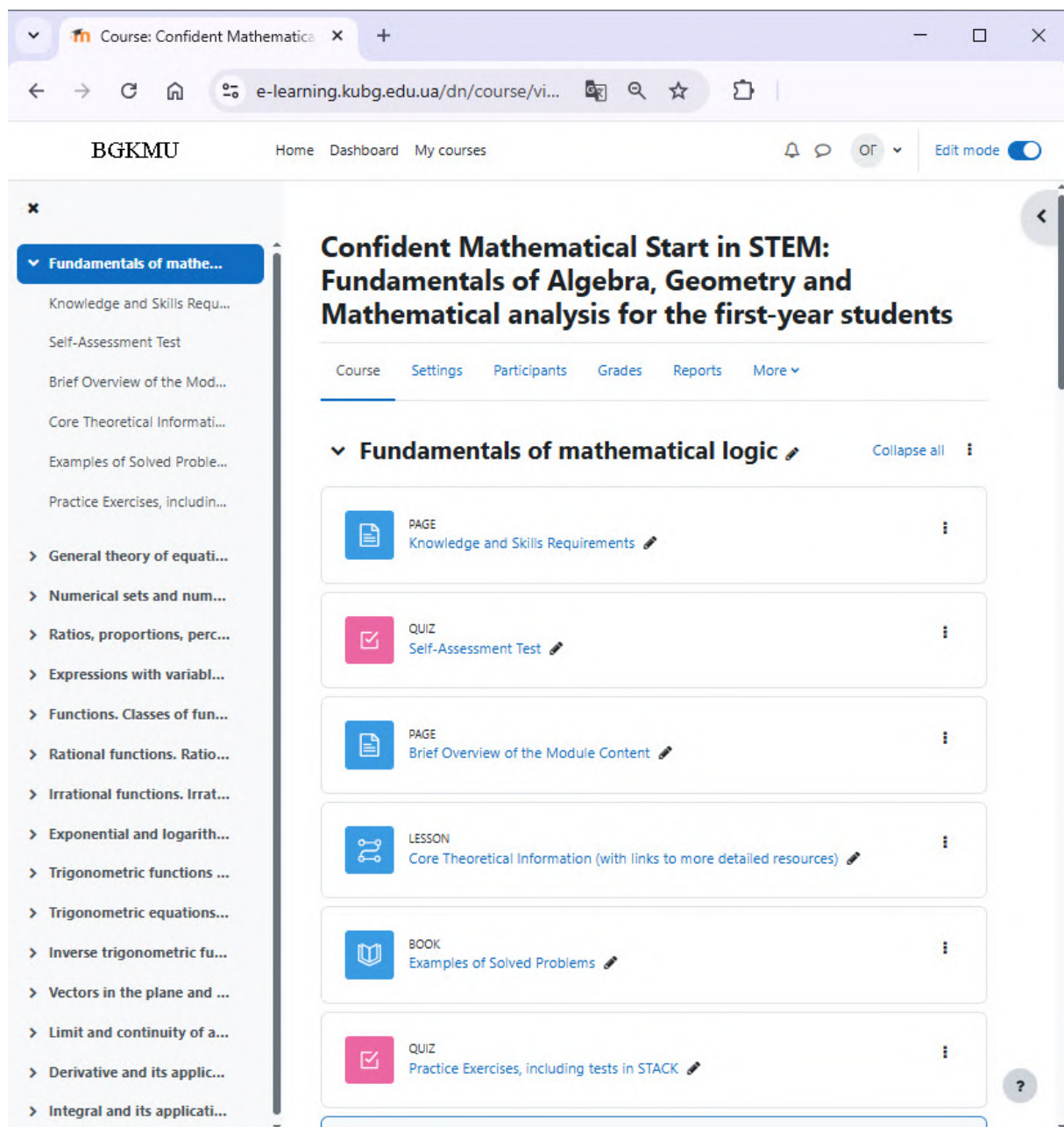


Figure 2. The module structure.

- enable dynamic interactions such as object movement in the GeoGebra applet, which offers clear advantages over static images;
- support different answer formats, including text, formula, mathematical expression, graph, etc;
- provide feedback and comments on the answers at each stage and the test results in general immediately, without delay;
- develop multi-level tasks in which students can receive instant feedback and explanations for each stage of the solution. This will help them gradually improve their skills, understand their mistakes, and correct their reasoning;

Question 1
 Not complete
 Marked out of 1.00

1. Differentiate $x^2 + 2 \cdot x - 1$ with respect to x .

2*x

Your last answer was interpreted as follows:
 $2 \cdot x$
 The variables found in your answer were: $[x]$

Incorrect answer.

2. Evaluate your derivative at $x = 3$.

6

Your last answer was interpreted as follows:
 6

Correct answer, well done.
 The answer to this part is correct, but you got the first part wrong, try both parts again

Figure 3. The example of a test in STACK.

- use variable task parameters to stimulate and support IBL. This encourages experimentation and adaptive feedback, which can be used to express hypotheses and explore general patterns.

In other words, STACK tests are used not only for assessment but primarily for learning, which increases its efficiency [34, 35].

However, it should be noted that preparing test items that shift the focus of assessment from reproduction, reproduction or use of routine procedures and trivial exercises to assessing conceptual understanding of mathematics, the ability to apply knowledge in a new situation, which is emphasised by researchers [34, 36], is not an easy task. In addition, the integration of STACK into content modules is also associated with specific challenges. Complex and time-consuming tasks include:

- developing well-structured tasks with variable parameters, considering various possible answer formats, such as numeric, symbolic, and graphical options;
- creating adaptive feedback for different common student errors, including automated prompts and comments that assist students in understanding their mistakes, to enhance assessment while teaching;
- STACK programming tasks require a basic understanding of the Maxima syntax, which is used for symbolic calculations within the STACK system.

To gather feedback on using thematic modules in self-study, students can engage in discussions on forums, complete surveys, and leave comments. Given the limited personal interaction between the lecturer and students and among students, it is crucial to provide alternative methods that foster an engaging and supportive learning environment.

Discussion forums play a crucial role in fostering social presence among students, helping them feel more connected to the learning community. Beyond these social benefits, forums also enhance cognitive presence by encouraging active participation in discussions and collaborative problem-solving in mathematics [28, 37, 38]. Consequently, forums are vital components of e-learning courses, as they provide a platform for meaningful interaction between students and teachers [39]. Furthermore, as noted by Durak and Ataizi [40], communication tools such as

forums, emails, and chat modules are essential for facilitating effective learning. This interactive approach not only increases students' knowledge levels but also enhances their communication skills and teamwork abilities.

It's essential to recognise that the course's content and style are crucial for achieving the established goals. The course offers supportive and friendly guidance, acting as an electronic tutor. This approach effectively supports students on their individual educational paths.

4. Conclusions

The gap between school graduates' mathematical knowledge and university program requirements, which manifests itself in cognitive, pedagogical, and psychological aspects, is one of the main obstacles to the successful education of students in STEM specialities. This problem is exacerbated during times of crisis, such as the pandemic and the war in Ukraine, which increase educational and learning losses.

An electronic adaptive training course that considers students' individual needs helps them independently eliminate knowledge gaps, thereby overcoming the cognitive gap and promoting their gradual adaptation to university education requirements. Integrating the STACK system for automated assessment allows for the implementation of adaptive learning trajectories.

The course's distance format, based on flexibility and personalisation, and its interactivity allow students to personalise their learning comfortably. This reduces anxiety and creates a comfortable learning environment, which is critically important for first-year students.

The training course in the Moodle LMS, which integrates adaptive tests based on STACK, provides individualised learning, personalised lecturers, and support for students' independent learning.

In the near future, it is planned to pilot the adaptive course with a broader audience of first-year STEM students, analyse its impact on their academic performance, and evaluate its effectiveness.

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A century of mathematics education at Kryvyi Rih State Pedagogical University: Honoring the past, shaping the future

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Abstract. This article examines the historical development of the mathematics department at Kryvyi Rih State Pedagogical University in Ukraine from its founding in the 1930s to the early 21st century. Drawing on extensive archival documents, oral histories, and scholarly analysis, it traces the department's evolution through the Soviet and post-Soviet eras, highlighting the key individuals, initiatives, and institutional factors that have shaped its trajectory. The analysis reveals a consistent commitment to excellence in mathematics teacher preparation, research, and community engagement, despite facing numerous challenges and transformations. In chronicling the department's past and present, the article illuminates the vital role of mathematics education in the socio-economic and cultural life of the Kryvyi Rih region. It concludes by reflecting on the enduring legacy and future prospects of the department in the context of ongoing educational reforms in Ukraine and beyond.

1. Introduction

Mathematics education has long been a cornerstone of the Ukrainian educational system, with a strong emphasis on fostering logical reasoning, problem-solving skills, and disciplinary knowledge at all levels of schooling [1, 2]. While the past century has witnessed dramatic transformations in Ukrainian politics, society, and education, mathematics teaching and learning have remained central to the mission and identity of the nation's pedagogical universities.

Among these institutions, Kryvyi Rih State Pedagogical University (KSPU) has played a particularly significant role in shaping mathematics education in central and eastern Ukraine. Founded in 1930 as the Kryvyi Rih Institute of Vocational Education, KSPU has grown into a major regional center for teacher training, educational research, and community outreach, with a long-standing reputation for excellence in mathematics and natural sciences [3].

At the heart of KSPU's contributions to the field of mathematics education lies its storied Department of Mathematics [4]. From its origins in the early Soviet period to its current position as a hub of innovation and international collaboration, the department has been a driving force



in advancing mathematical knowledge, pedagogy, and scholarship in the Kryvyi Rih region and beyond. Its faculty and graduates have made remarkable achievements in research, teaching, educational leadership, and public service, leaving an indelible mark on the intellectual and cultural life of the university and the wider community.

This article presents a comprehensive study of the KSPU Department of Mathematics from its establishment in the 1930s to the early 21st century. Drawing on a wealth of archival documents, oral history interviews, and secondary literature, it offers an in-depth analysis of the department's development over time, situated within the broader context of Soviet and post-Soviet transformations in education and society. Specifically, the article addresses the following questions:

- RQ1: How did the KSPU Department of Mathematics evolve in its organizational structure, curricular offerings, and pedagogical approaches from the 1930s to the 2000s, and what internal and external factors shaped these changes?
- RQ2: Who were the key individuals that led the department and made significant contributions to mathematical research, teacher preparation, and educational reform during this period, and what was the nature and impact of their work?
- RQ3: How did the department navigate the challenges and opportunities posed by major political, economic, and social upheavals in Ukraine, including World War II, the collapse of the Soviet Union, and the post-Soviet transition?
- RQ4: In what ways did the department engage with the local community and collaborate with regional, national, and international partners to enhance mathematics teaching and learning within and beyond the university?
- RQ5: What lessons can be drawn from the KSPU Department of Mathematics' historical experiences for understanding the role and potential of university-based mathematics education in the 21st century?

By critically examining the KSPU Department of Mathematics as a revelatory case of mathematics education in the Soviet and post-Soviet contexts, this article makes several contributions to historical and contemporary scholarship. First, it deepens our understanding of how political, ideological, and institutional forces have intersected to shape the development of mathematics education in Ukraine and the post-Soviet space more broadly [5–7]. Second, it highlights the agency and resilience of local actors, especially mathematics educators, in navigating and responding to macro-level changes and pressures over time. Third, it generates insights into the complex dynamics of continuity and change in educational policy and practice, and the vital importance of balancing tradition and innovation in mathematics teaching and teacher preparation.

Finally, by situating the KSPU Department of Mathematics within the broader landscape of international research on mathematics education, the article illuminates the ways in which the department's trajectory both reflects and departs from global trends and challenges in the field [8]. In doing so, it underscores the value of historically and contextually grounded analyses of mathematics education at the local and institutional level, and the need for more comparative and cross-national studies that can inform educational policy and practice in an increasingly interconnected world.

2. Historical context: mathematics education in the Soviet Union and post-Soviet Ukraine

The history of the KSPU Department of Mathematics is inextricably linked to the broader arc of political, social, and educational developments in Soviet and post-Soviet Ukraine. Mathematics education in the Soviet Union was characterized by a strong emphasis on

fundamental knowledge, logical reasoning, and problem-solving skills, with a rigorous and standardized curriculum that prioritized abstract thinking and applications to science and engineering [5, 9]. Soviet mathematics teaching was supported by a well-developed system of pedagogical institutes, specialized schools, and extracurricular activities, which aimed to identify and nurture mathematical talent from an early age [1, 9].

At the same time, Soviet mathematics education was deeply influenced by Marxist-Leninist ideology and the centralized planning of the command economy, which privileged collectivism, social utility, and the needs of the state over individual interests and aspirations [5]. Mathematics teachers were expected to instill in their students not only subject knowledge but also communist values and loyalty to the regime, while also grappling with persistent challenges such as shortages of qualified instructors, inadequate facilities and resources, and the pressures of ideological conformity [1].

In the post-World War II period, Soviet mathematics education underwent significant expansion and modernization, as the country sought to compete with the West in science and technology. Reforms in the 1960s and 1970s introduced new topics such as set theory, probability, and computing into the mathematics curriculum, while also experimenting with student-centered pedagogies and internationalization through participation in conferences and exchanges [10]. However, these efforts were often hampered by political and bureaucratic obstacles, as well as resistance from conservative elements within the educational establishment [5].

The collapse of the Soviet Union in 1991 ushered in a new era of profound transformation in Ukrainian mathematics education. The transition to a market economy and democratic political system, as well as the assertion of Ukrainian national identity and language, posed both challenges and opportunities for educational institutions and practitioners [11]. On the one hand, the post-Soviet period brought greater academic freedom, international collaboration, and access to new technologies and resources for mathematics teaching and research. On the other hand, it also led to significant disruptions in funding, governance, and social cohesion, as well as a brain drain of talented mathematicians and educators to other countries [12].

In the face of these challenges, Ukrainian mathematics educators have sought to balance the preservation of the strengths of the Soviet system, such as its emphasis on fundamental knowledge and problem-solving, with the need for innovation and adaptation to the demands of the 21st century. Reforms in the 2000s and 2010s have aimed to align Ukrainian mathematics education with European and international standards, promote the use of technology and interactive teaching methods, and foster greater integration between mathematics and other STEM disciplines [13]. At the same time, there have been ongoing debates and struggles over issues such as the language of instruction, the role of private and non-formal education, and the preparation and professional development of mathematics teachers.

It is against this complex and dynamic backdrop that the story of the KSPU Department of Mathematics unfolds. As a leading center of mathematics education in central and eastern Ukraine, the department has both shaped and been shaped by the broader historical and contemporary forces that have defined the field over the past century. By examining its specific institutional trajectory and the experiences and contributions of its faculty and students, this article seeks to shed light on the challenges, achievements, and future prospects of mathematics education in Ukraine and beyond.

3. Methodology

This study employs a qualitative case study design to investigate the history and development of the KSPU Department of Mathematics from the 1930s to the 2000s. Case study research is well-suited for exploring complex, context-dependent phenomena through in-depth analysis of a bounded system, using multiple sources of data and a holistic, interpretive approach [14–16]. In this study, the KSPU Department of Mathematics serves as an instrumental case [15] that

illuminates broader issues and themes in the history of mathematics education in Soviet and post-Soviet Ukraine.

The primary data sources for this study include:

- (i) Archival documents from the KSPU institutional archives, such as departmental records, course syllabi, faculty personnel files, student transcripts and theses, conference proceedings, and correspondence. These materials provide valuable insights into the formal policies, practices, and achievements of the department over time.
- (ii) Oral history interviews with 15 current and former faculty members and administrators of the KSPU Department of Mathematics, conducted by the author between 2018 and 2020. Participants were selected through purposive and snowball sampling to represent different generations, specializations, and roles within the department. Semi-structured interviews explored participants' educational and professional backgrounds, experiences and perspectives on the department's history and culture, and reflections on the past, present, and future of mathematics education in Ukraine. Interviews were conducted in Ukrainian or Russian, audio-recorded, and transcribed verbatim for analysis.
- (iii) Secondary sources on the history of mathematics education in the Soviet Union and Ukraine, as well as international scholarship on mathematics education reform and teacher preparation. These sources provide important contextual information and comparative perspectives for interpreting the KSPU case.

Data analysis followed an iterative process of thematic coding, constant comparison, and triangulation [14, 16]. Archival documents and interview transcripts [17] were first coded inductively to identify key events, actors, and patterns related to the research questions. These initial codes were then organized into broader categories and themes, and compared across data sources and with the existing literature to enhance the reliability and validity of the findings [14]. Particular attention was paid to analyzing continuity and change in the department's organizational structure, curricular content, pedagogical approaches, research activities, and external partnerships over time, as well as the role of individual agency and institutional constraints in shaping these developments.

To ensure the trustworthiness of the study, several strategies were employed, including member checking of interview transcripts and preliminary findings with participants, peer debriefing with colleagues in the field of mathematics education and history of education, and maintaining an audit trail of data collection and analysis procedures [18]. The study also acknowledges its limitations, such as the potential for recall bias in participants' accounts, the selective nature of archival preservation, and the challenges of generalizing from a single case study.

4. Founding and early years of the KSPU Mathematics Department (1930s-1950s)

The establishment of the KSPU Mathematics Department in the early 1930s marked a significant milestone in the development of higher education in the Kryvyi Rih region. Founded in 1930 as the Kryvyi Rih Institute of Vocational Education (KRIVE), KSPU was part of a broader initiative by the Soviet government to expand access to pedagogical training and professionalize the teaching force in Ukraine and other Soviet republics [1]. The institute initially comprised two main departments: Physics and Mathematics (figure 1), and History and Philology, as well as a workers' faculty that prepared students for higher education [17, p. 9].

The first head of the Mathematics Department was Professor Lev Antonovych Kareta, who served from 1933 to 1936 [17, p. 39]. Kareta was a prominent mathematician who had previously taught at the Kamianets-Podilskyi Institute of People's Education and was known for his research in differential equations and mathematical physics [19, 20]. Under Kareta's leadership, the department established a rigorous curriculum that emphasized a solid foundation

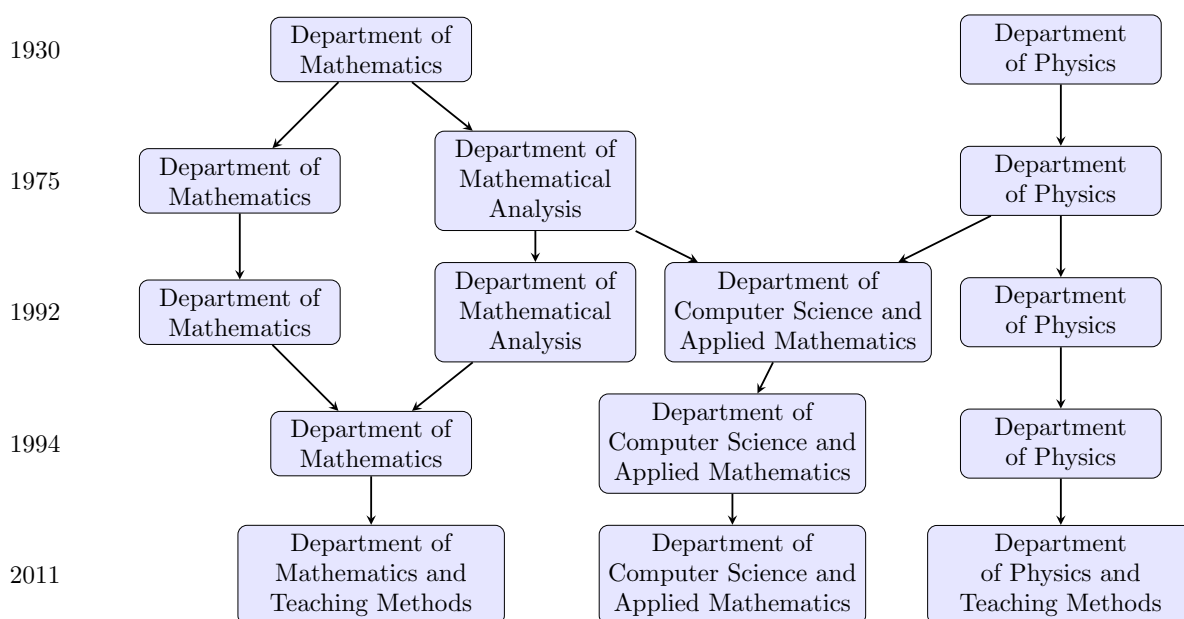


Figure 1. KSPU Mathematics Department genealogy [17, p. 17].

in mathematical analysis, algebra, and geometry, as well as pedagogy and teaching methods. The program aimed to prepare well-rounded mathematics teachers for secondary schools, with a strong grounding in both content knowledge and pedagogical skills.

Despite the challenges of limited resources and political instability in the 1930s, the Mathematics Department attracted talented students and faculty from across the Soviet Union. Departmental records show that the student body in the early years was diverse in terms of geographic origin, gender, and social background, with many students coming from worker and peasant families and receiving state stipends to support their studies. The faculty also included a mix of experienced educators and promising young researchers, such as Borys Mykhailovych Yakhnin, who would go on to become a leading figure in the department for several decades [17, p. 133].

In addition to its regular coursework, the Mathematics Department also engaged in a range of extracurricular activities and collaborations during its early years. For example, faculty and students participated in regional and national mathematics competitions and conferences, such as the All-Ukrainian Mathematics Olympiad held in Kharkiv in 1935. The department also organized public lectures and workshops for local teachers and students, as well as cultural events and celebrations that helped to foster a sense of community and social responsibility among its members.

The outbreak of World War II in 1941 brought significant challenges and disruptions to the Mathematics Department and KSPU as a whole. Many students and faculty members were mobilized for military service or evacuated to other parts of the Soviet Union, while the institute's facilities were damaged by bombing and occupation [21]. Yet even in these difficult circumstances, the department strived to maintain its educational and research activities, with faculty members continuing to teach courses and advise students remotely or in makeshift classrooms.

In the immediate post-war years, the Mathematics Department played a key role in the reconstruction and renewal of KSPU and the Kryvyi Rih region more broadly. With the return of demobilized soldiers and evacuees, enrollment in the department increased significantly, necessitating the expansion of faculty and facilities. The department also stepped up its efforts



Figure 2. The institute building, which housed the mathematics department from its founding (from KSPU Museum collection).



Figure 3. The 12th graduating class of the Physics-Mathematics Faculty, featuring both full-time and correspondence students who studied during the post-war reconstruction period (from KSPU Museum collection).

to provide in-service training and support for local mathematics teachers, many of whom had interrupted their careers during the war and needed to update their knowledge and skills.

The late 1940s and early 1950s saw a gradual stabilization and consolidation of the Mathematics Department, as well as the introduction of new initiatives and directions. In 1947, Borys Mykhailovych Yakhnin was appointed as head of the department, a position he would hold until 1972 [22]. Yakhnin was a talented mathematician and educator who had graduated from Dnipropetrovsk University and had a particular interest in the theory of functions and functional analysis. Under his leadership, the department expanded its course offerings to include more advanced topics such as complex analysis, differential equations, and probability theory, and strengthened its ties with other mathematical institutions and scholars in the Soviet Union.

One of the most significant initiatives of this period was the development of the department's first specialized mathematics school for gifted secondary school students. Established in 1957 under the leadership of Yakhnin and other faculty members, the school provided advanced coursework and mentoring for talented young mathematicians from Kryvyi Rih and the surrounding region, and served as a pipeline for recruiting top students to the university's mathematics program. Many graduates of the school went on to become leading mathematicians, educators, and researchers in Ukraine and beyond, including Mykola

Oleksandrovych Rashevskyi, who would later serve as associate professor of the department [17, pp. 104-105].

The 1950s also saw the strengthening of the department's research profile and international collaborations. Faculty members published numerous articles in leading Soviet and international journals, and participated in conferences and symposia. The department also hosted visiting scholars and delegations from other countries of Eastern Bloc.

By the end of the 1950s, the KSPU Mathematics Department had established itself as a thriving and dynamic center of mathematical education and research, with a strong reputation both within Ukraine and across the Soviet Union. Its faculty and graduates were making significant contributions to a wide range of fields, from pure and applied mathematics to pedagogy and teacher training. At the same time, the department faced ongoing challenges, such as the need to adapt to changing political and ideological demands, to cope with material shortages and bureaucratic constraints, and to balance the competing priorities of teaching, research, and service.

As the department entered the 1960s, it was well-positioned to take advantage of new opportunities and directions in Soviet mathematics and education, while also grappling with the complex legacies of its past and the uncertainties of its future. The following decades would bring both continuity and change, as the department navigated the transformative events of the late Soviet and post-Soviet eras, and sought to redefine its role and identity in a rapidly changing world.

5. Expansion and innovation in the Soviet Era (1960s-1980s)

The 1960s marked a period of significant expansion and innovation for the KSPU Mathematics Department, as it sought to keep pace with the rapid developments in Soviet science and technology. Under the leadership of Borys Mykhailovych Yakhnin, who continued to serve as head of the department until 1972, the department introduced a range of new courses and programs to meet the growing demand for mathematical expertise in fields such as physics, engineering, economics, and computer science [23].

One of the most notable developments of this period was the establishment of a new specialization in computational mathematics, which aimed to train students in the use of computers and numerical methods for solving complex mathematical problems. The department acquired its first computer, a Soviet-made Ural-1, in 1961, and began to offer courses in programming, algorithms, and data structures, as well as more advanced topics such as optimization and mathematical modeling. The computational mathematics program attracted strong interest from students and employers alike, and helped to position the department at the forefront of the emerging field of computer science in Ukraine.

Another area of growth and innovation in the 1960s was the department's research in mathematical physics and the theory of functions. Led by talented young researchers such as Oleksandr Ivanovych Polovyna [17, pp. 97-103], the department made significant contributions to the study of boundary value problems, integral equations, and approximation theory, among other topics [24]. The department also strengthened its collaborations with other leading institutions in the Soviet Union, such as the Institute of Mathematics of the Ukrainian Academy of Sciences in Kyiv and the Steklov Institute of Mathematics in Moscow, through joint research projects, conferences, and publications.

The department also intensified its efforts to promote mathematics education and outreach in the Kryvyi Rih region and beyond. In 1972, the department organized the first regional mathematics competition for secondary school students, which attracted participants from across central and eastern Ukraine. The competition helped to identify and nurture mathematical talent at an early age, as well as to strengthen the department's ties with local schools and communities.



Figure 4. Distinguished methodologist Hryhorii Petrovych Bevz (center) conducting a seminar for mathematics faculty, with department members including I. F. Safir, L. O. Chernykh, O. I. Polovyna, and others.

The 1980s saw the department continue to innovate and adapt to the changing needs and opportunities of the late Soviet era. One of the most significant developments of this period was the introduction of new courses and programs in computer science and information technology, reflecting the growing importance of these fields in the Soviet economy and society [25]. The department established a new section of Informatics in 1985, which offered undergraduate degree in computer science education [17, pp. 110-116], and collaborated closely with industry partners such as the Kryvyi Rih Metallurgical Plant and the Kryvyi Rih Mining and Processing Plant.

The 1980s also witnessed the emergence of a new generation of talented mathematicians and educators at the department, many of whom had been trained in the department's own graduate programs. Among the most prominent of these young scholars was Volodymyr Mykolayovych Solovyov, who had graduated from KSPU in 1975 and had gone on to become a leading researcher in the field of mathematical modeling and nonlinear dynamics [26, 27]. In 1992, Solovyov was appointed as head of the newly established Department of Applied Mathematics and Computer Science, which brought together faculty and students from across the university to work on interdisciplinary problems at the intersection of mathematics, physics, and computer science (figure 1).

Despite the many challenges and uncertainties of the late Soviet era, including the growing economic and political crisis that would ultimately lead to the collapse of the Soviet Union in 1991, the KSPU Mathematics Department remained a vibrant and dynamic community of scholars and students throughout the 1980s. Its faculty and graduates continued to make significant contributions to mathematical research and education, both in Ukraine and internationally, and to engage actively with the broader scientific and cultural life of the region.

As the department entered the 1990s, it faced a new set of challenges and opportunities in the post-Soviet era, including the need to adapt to a market economy, to forge new partnerships and collaborations both within Ukraine and abroad, and to redefine its role and identity in a rapidly globalizing world. Yet the strong foundations of excellence in teaching, research, and service that had been built over the previous decades would serve the department well as it navigated this new and uncertain terrain.



Figure 5. Faculty and students celebrating the Last Bell ceremony, featuring department heads S. V. Utkina (Dean), O. I. Polovyna, V. M. Solovyov, L. S. Naryshkina, O. V. Vikhrova (Bych) and founding faculty members.

6. Navigating the post-Soviet transition (1990s-2000s)

The collapse of the Soviet Union in 1991 marked a watershed moment in the history of the KSPU Mathematics Department, as it did for higher education and society as a whole in Ukraine. The transition from a centrally planned to a market-based economy, the assertion of Ukrainian national identity and sovereignty, and the opening up of the country to the West all posed significant challenges and opportunities for the department as it sought to adapt and thrive in a new era [28].

One of the most pressing issues facing the department in the early 1990s was the need to modernize its curriculum and pedagogy to reflect the latest international standards and practices in mathematics education. This required a significant investment in new textbooks, teaching materials, and technology, as well as a fundamental rethinking of the department's approach to teaching and learning [29]. Under the leadership of Oleksandr Ivanovych Oleinikov [30], who had become head of the department in 1994, the department embarked on a major reform effort to align its programs with the Bologna Process and other European higher education initiatives, and to introduce more student-centered and research-based pedagogies.

Another key priority for the department in the post-Soviet era was to expand its international collaborations and partnerships. With the lifting of travel restrictions and the opening up of new opportunities for academic exchange, the department began to actively seek out collaborations with leading universities and research centers in Europe, North America, and beyond. These collaborations took many forms, from joint research projects and publications to faculty and student exchanges, summer schools, and conferences.

In Ukraine, the department maintains active partnerships with Dragomanov Ukrainian State University (Kyiv), Vinnytsia Mykhailo Kotsiubynskyi State Pedagogical University, Cherkasy National University, Central Ukrainian State University, and the Academy of Cognitive and Natural Sciences.



Figure 6. The 85th anniversary celebration of the faculty, demonstrating the continuity of mathematical education traditions across generations.

At the same time, the department also faced significant challenges in adapting to the new economic and political realities of post-Soviet Ukraine. The country's transition to a market economy led to a sharp decline in state funding for higher education, which forced the department to seek out new sources of revenue and to become more entrepreneurial in its approach to research and teaching [31]. The department began to offer new fee-based programs and services, such as continuing education courses for teachers, as well as consulting and contract research for private companies and government agencies.

The department also grappled with the complex legacies of the Soviet era, including the need to redefine its intellectual and institutional identity in a new political and cultural context. This involved a critical reexamination of the department's history and traditions, as well as a renewed commitment to academic freedom, institutional autonomy, and democratic governance. The department played an active role in the wider process of educational reform and democratization in Ukraine, with faculty members serving on national and regional committees, and contributing to public debates on issues such as language policy, and the role of higher education in social and economic development [17, pp. 101-102].

Despite these challenges, the department continued to make significant strides in research and education throughout the 1990s and early 2000s. In 1998, the department was recognized as a Center of Excellence in Mathematics by the Ukrainian Ministry of Education and Science, in recognition of its outstanding contributions to research and teaching. The department also played a key role in the KSPU accreditation on the 4th (university) level in 1999.

In the early 2000s, the department also began to expand its reach and impact in the area of teacher education and professional development. With the introduction of new national standards for mathematics education in Ukraine, the department developed a range of innovative programs and resources to support the professional learning and growth of mathematics teachers at all levels, from pre-service to in-service. These included a new Master's program in Mathematics Education, which aimed to prepare future teacher leaders and researchers, as well as a network of regional teacher training centers.

Another key initiative of the 2000s was the establishment of the Academy of Cognitive and Natural Sciences, a professional organization that brought together scientists, educators, and researchers from across the Ukraine to promote mathematical and science literacy and excellence [32]. The society organized a range of workshops, as well as an annual International Conference on Mathematics, Science and Technology Education that attracted participants from around the world [33].

As the KSPU Mathematics Department entered the second decade of the 21st century, it faced new challenges and opportunities in an increasingly globalized and interconnected world. Yet it continued to draw on its long and rich history of excellence and innovation, as well as its deep commitment to serving the needs of students, educators, and communities in the Kryvyi Rih region and beyond. As the department looked to the future, it remained well-positioned to play a leading role in advancing the frontiers of mathematical knowledge and education, and in shaping the next generation of scholars, teachers, and leaders in the field.

7. Contributions to regional mathematics education

Throughout its history, the KSPU Mathematics Department has played a vital role in promoting mathematical literacy, excellence, and innovation in the Kryvyi Rih region and beyond. Through its teaching, research, and outreach activities, the department has made significant contributions to the development of mathematics education at all levels, from primary to higher education, and has helped to shape the intellectual and cultural life of the region in profound ways.

One of the department's most enduring contributions has been its preparation of highly qualified mathematics teachers for the region's schools. Over the years, thousands of KSPU graduates have gone on to teach mathematics at all grade levels, bringing with them a deep knowledge of the subject matter, a passion for teaching and learning, and a commitment to fostering mathematical literacy and critical thinking skills in their students [34]. Many of these graduates have also taken on leadership roles in their schools and communities, serving as department chairs, curriculum developers, and mentors to new teachers [17, chap. 3, 4].

The department has also been a key player in the development of mathematics curricula and teaching materials for use in regional schools. In the 1960s and 1970s, faculty members worked closely with the Kryvyi Rih Regional Department of Education to develop new textbooks and instructional resources that reflected the latest advances in mathematics education research and practice. More recently, the department has been involved in the creation of digital learning resources and platforms, such as the Online Mathematics School, which provides high-quality mathematics instruction and support to students and teachers across the region.

Beyond the Online Mathematics School, the department has developed an extensive ecosystem of digital learning resources. Faculty members have created over 16 specialized online courses on the Moodle platform, including: "Information and Communication Tools for Teaching Mathematics" (T. H. Kramarenko), "Mathematical Analysis for Physics and Computer Science Specialties" (K. V. Polhun), "Probability Theory and Mathematical Statistics" for multiple specialties, "Higher Mathematics" for engineering students (H. M. Bilousova). These courses serve over 500 students annually across different specialties, with the department faculty serving as course creators, technical administrators, and content developers.

In addition to its work with schools, the department has also been actively involved in promoting mathematics education and outreach in the wider community. This has included organizing public lectures, workshops, and competitions aimed at engaging students and members of the public in mathematical exploration and discovery.

The department's outreach activities include specific, long-running initiatives:

- (i) The Regional Mathematics Olympiad, established in 1972, which annually attracts 200+ participants from central and eastern Ukraine
- (ii) The student research circle "Olympiad Problems in Mathematics", whose members have won prizes at national competitions
- (iii) The All-Ukrainian Scientific-Methodological Conference "Innovative ICT in Mathematics Education", which in its inaugural year (2011) brought together 130 students and young scientists from over 20 Ukrainian cities [35]

- (iv) Teacher training seminars conducted across Dnipropetrovsk Oblast: Dovhyntsi district (3 seminars), Saksahan district (3), Zhovtneve district (4), and single seminars in Central City, Inhulets, Apostolove, and Tomakivka districts
- (v) Master classes on ICT integration in mathematics teaching, delivered regularly at the KSPU Teacher Training Center

One of the department's most significant outreach initiatives has been its support for the professional development and lifelong learning of mathematics educators. Through its graduate programs, research collaborations, and continuing education offerings, the department has provided opportunities for teachers to deepen their knowledge and skills, stay up-to-date with the latest developments in the field, and connect with colleagues and experts from around the world. The department has also been involved in the development of national and regional standards and frameworks for mathematics teacher education, helping to ensure that pre-service and in-service teachers have the knowledge, skills, and dispositions needed to be effective and innovative educators.

The department's research activities have also had a significant impact on mathematics education in the region and beyond. Faculty members have conducted cutting-edge research on a wide range of topics, from the foundations of mathematics and the history of mathematical thought to the applications of mathematical knowledge in fields such as physics, computer science, and economics. The department has also been a leader in the development of new research methodologies and tools, such as mathematical modeling and simulation, data analysis and visualization, and educational technology.

Many of these research projects have had direct implications for mathematics education in the region, informing the development of new curricula, pedagogical approaches, and assessment strategies. For example, in the 1980s and 1990s, the department's research on problem-solving and heuristics led to the development of new instructional materials and training programs for teachers, aimed at helping students develop their mathematical thinking and reasoning skills. More recently, the department's research on the use of digital tools and platforms in mathematics education has informed the design and implementation of innovative online and blended learning programs [36].

The department's research has produced concrete methodologies with direct educational applications:

- *Complex systems theory and crisis prediction (Solovyov School, 1990s-present)*: led by Professor V. M. Solovyov, this research school applies econophysical and synergetic approaches to model complex systems. Key outputs include development of adaptive indicators for early warning of crisis phenomena in economic systems, Markov chain methods for forecasting complex systems, and entropic analysis methods for global banking systems.
- *Competency-based mathematics education (2015-2019)*: under the leadership of Professor V. V. Korolskyi, the department completed the comprehensive research project "Theoretical-Methodological Foundations and Technologies for Implementing Competency-Based Approach in Mathematics Teacher Training". This resulted in: 3 monographs (2 in Ukraine, 1 international), 8 textbooks and teaching aids, development of competency-oriented problem banks for engineering students, and new assessment strategies implemented across 5 mathematics courses.
- *Educational technology integration*: Faculty have pioneered blended learning approaches, publishing the seminal work "Innovative Information and Communication Technologies for Teaching Mathematics" [36], which has become a reference for mathematics educators nationwide.

Through these and other contributions, the KSPU Mathematics Department has helped to shape the intellectual and cultural landscape of the Kryvyi Rih region, and to promote the value and importance of mathematics education for individual and societal well-being. Its commitment to excellence, innovation, and service has inspired generations of students, educators, and researchers, and has helped to build a strong and vibrant community of mathematics learners and practitioners.

As the department looks to the future, it remains committed to its mission of advancing mathematical knowledge and education, and to serving the needs of the region and beyond. Through its ongoing research, teaching, and outreach activities, the department is well-positioned to continue making significant contributions to the field, and to help shape the future of mathematics education in Ukraine and around the world.

8. Conclusion

The history of the KSPU Mathematics Department is a story of resilience, adaptability, and excellence in the face of profound social, political, and intellectual transformations. From its founding in the early Soviet era to its current position as a leading center of mathematical research and education in independent Ukraine, the department has consistently demonstrated a deep commitment to advancing mathematical knowledge, preparing highly qualified teachers and researchers, and serving the needs of students and communities in the Kryvyi Rih region and beyond.

Through its innovative research, teaching, and outreach activities, the department has made significant contributions to the development of mathematics education in Ukraine and internationally. Its faculty and graduates have been at the forefront of efforts to modernize curricula and pedagogies, develop new instructional resources and technologies, and promote mathematical literacy and problem-solving skills at all levels of education. The department has also been a key player in shaping national and regional policies and practices related to mathematics education, teacher training, and STEM workforce development.

At the same time, the department's history also reflects the broader challenges and opportunities facing higher education and society in Ukraine and the post-Soviet space. From the ideological and material constraints of the Soviet era to the economic and political upheavals of the post-Soviet transition, the department has had to navigate complex and often turbulent terrain, while also striving to maintain its core values and commitments. Its success in doing so is a testament to the dedication, creativity, and resilience of its faculty, staff, and students, as well as to the enduring importance of mathematics as a vital field of human knowledge and endeavor.

As the KSPU Mathematics Department looks to the future, it faces new challenges and opportunities in an increasingly interconnected and rapidly changing world. The emergence of new technologies, the globalization of higher education, and the shifting demands of the knowledge economy all present both risks and possibilities for the department and the wider field of mathematics education. Yet the department's long history of adaptation and innovation, as well as its deep roots in the intellectual and cultural life of the Kryvyi Rih region, provide a solid foundation on which to build and grow in the years ahead.

Ultimately, the story of the KSPU Mathematics Department is a powerful reminder of the vital role that mathematics education plays in shaping the minds, lives, and futures of individuals and societies. Through its tireless efforts to advance mathematical knowledge, nurture talent, and serve the public good, the department has helped to unlock the power of mathematics as a tool for understanding the world, solving problems, and creating new opportunities. As such, its legacy and impact will continue to be felt for generations to come, both in Ukraine and around the world.

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Mathematics for digital signal processing: series and integrals of Fourier in professional training

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Mathematics for digital signal processing: series and integrals of Fourier in professional training

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Abstract. The article presents the features of applying mathematical knowledge in the professional training of modern specialists in digital production transformation. Accordingly, the article investigates the methodological strategies and practices of using the Fourier series in the educational process based on the developed pedagogical system, “Constructive-interpretive concept of the development of mathematical knowledge and thinking of a future engineer”, with the integrative use of digital technologies, including visualisation. The integrative use of the Fourier series and digital technologies contributes to the development of a system of professionally significant intellectual qualities in a future specialist, among which the relevant ones are the abilities to: modeling, finding solutions, calculation (in the sense of complex calculations), interpretation, construction, anticipation (forecasting), representation, analysis and synthesis, innovative activity, conceptualization, scientificization. The professionalisation of specialists through a practically oriented study of mathematics and the application of digital technologies, as well as the mastery of interconnected processes such as mathematization, cognitivation, digitalization and scientificization of production in the technosphere, management, design and monitoring are considered systemic factors in the digital transformation of production. These factors are also conditions for increasing its efficiency, competitiveness, environmental friendliness and innovative development. According to the results of the conducted pedagogical research, the presence of difficulties in solving problems of applied content was determined in future specialists of engineering specialties, which are minimized when using digital technologies and the practical orientation of mathematical knowledge. At the final stage of the study, the positive dynamics of the results of educational achievements were determined, aimed at the development of special mathematical knowledge and the formation of creative abilities, as well as their practical application.

1. Introduction

The use of digital technologies in the modern technologically capacious, technogenic, and science-intensive production of the sixth technological order contributes to its further cognitization [1, 2]. The indicated trends in the cognitization of production and the socio-cultural sphere determine one of the defining issues of the postmodern era – this is the need to form a



competent intellectualized specialist. It is such a specialist who can flexibly and creatively solve complex technical and technological problems and act as an innovator [3,4]. In addition to special and general knowledge, the defining essential professional and personal characteristic of such a competent specialist is his professional thinking, which is formed on the basis of revealing both practical aspects of activity and through familiarization with fundamental natural, mathematical, and technical laws and phenomena. Consequently, in modern digital educational realities, both fundamentalization and practical orientation and concretization and integration of mathematical and technical knowledge are system-organizing for the professional training of the future engineer.

When training the future engineer, we paid special attention to his study of Fourier series as a fundamental mathematical concept. This knowledge is useful for describing, modeling, and researching various technical, sociocultural, and natural processes and objects. In this aspect, the specialist's knowledge of complex mathematical phenomena, which can have direct application in modeling and creating technical systems, and can also be used for their representation, description, improvement, analysis of functioning, etc., acquires special professional significance.

Fourier series plays an important role in the professional activities of an engineer [5]. One of the motives for introducing the Fourier series into the educational process, as the author claims, is the solution of differential equations that describe forced oscillations and the approximation of periodic functions.

According to Zhu et al. [6], the Fourier series emerged or gained a new life in the field of telecommunications technology, particularly in connection with the digitization of data (signals) for their transmission. Since the models of harmonic signals, built based on the time domain, in most cases have a complex resolution, they are built using integrals.

In the study by Hochmuth and Peters [7], a praxeological methodology was developed to analyze mathematical practices in signal theory courses. The authors identified how students' solutions to signal theory problems can be analyzed and understood based on the Anthropological Theory of Didactics and the identification of two institutional mathematical discourses. The study also demonstrates that epistemological relationships between mathematics and engineering are important for detailed description and analysis of mathematical practices in electrical engineering contexts.

Such views on the introduction of the Fourier series into the educational process are confirmed in the study of Rønning [8], which is based on the analysis of textbooks and one widely used mathematics textbook for engineers, as well as a textbook and video lectures on signal theory. This study takes into account previous studies that showed the lack of connection between mathematics courses and engineering courses with the application of mathematics.

In the scientific-pedagogical literature, the role of fundamental and practically oriented knowledge of mathematical phenomena, namely the Fourier series, as part of the theoretical and methodological training of a future specialist and in the system of his practically oriented knowledge and professional thinking is not sufficiently highlighted. The above-mentioned aspects of problematization, which reflect the significance of the Fourier series for the professional training of future engineers and the organization of modern production, define the problem we have indicated as relevant and, accordingly, significant for both pedagogical theory and practice.

Therefore, *the purpose* of the article is to investigate methodological strategies and practices of using Series and Integrals of Fourier in the professional training of a modern specialist for Digital Signal Processing.

2. Methodology

In this study, a system of methods was used, among which the following were the most important: systemic, pedagogical, modeling, mathematical, hermeneutic, digital technologies, etc.

Of the pedagogical methods, we used: competency and axiological approaches; methods

of pedagogical integration and pedagogical hermeneutics; interactive teaching aids; surveys; pedagogical experiment, and others.

Mathematical methods are represented by the theory of Fourier series, the theory of Fourier integrals, mathematical models, the method of fast Fourier transform, Walsh functions, Fisher's criterion, and others.

Digital technologies are represented by visual mathematical models, which are developed in computer mathematics systems MathCAD, Maple.

3. Results and discussion

In many countries, engineering training programs face a high level of inability to master mathematical knowledge, which can be an important reason for students to leave their studies (student dropout) [9]. Some engineering students consider mathematics irrelevant, as something that distracts attention from engineering subjects. In the study, we did not consider the debatable issues of this topic. The goal was to analyze the issues of teaching students such complex concepts as the Fourier series.

Based on the methodological understanding of pedagogical experience and practice, the "Constructive-interpretive concept of the development of mathematical knowledge and thinking of a future engineer" was developed, which is used in the educational process for the integrative formation of mathematical and professional competencies of a future engineer (figure 1). The essence of this concept lies in the integrative development and professional direction of two relatively autonomous "cognitive blocks" consisting of certain systems of thinking and knowledge, namely: 1) analytical-synthetic, discursive-logical thinking and mathematical cognitive skills, which mathematics develops; and 2) constructive, reproductive, sensory-intuitive thinking, which underlie the engineer's design activity. The professional and intellectual condition of this integration is the actualization of interpretative and innovative thinking, as well as the creative potential of the individual. In educational practice, such mathematically-constructive "cognitive-knowledge integration" of the above-mentioned cognitive styles, skills, and knowledge is implemented through the active and systematic use of digital technologies in educational and professional practices, professional case systems, professionally-oriented dialogues aimed at actualizing the interpretative potential of the individual, as well as the use of collaborative and problem-based learning, interactive tools, and reflections. In the methodological system of this concept, special knowledge about Fourier series is revealed and highlighted as analytical-synthetic, methodological-conceptualizing, and "technological-modeling" mathematical cognitive tools. This contributes to the formation of the cognitive potential of the future engineer and, above all, is aimed at the development of his professional thinking as a relevant component of his professional competence. Intellectually constructive and analytical-synthetic potentials of special knowledge about Fourier series are revealed, interpreted, professionally directed on the basis of the application of visualization and animation technologies. Thus, from the point of view of methodology, we form an "epistemological motivational axis" – "mathematics – innovations – interpretations – professional intelligence and practices – creativity, activation of motivation for learning and activity". The systemic factors of this integration are innovations, interpretativity and digital technologies. This concept differs from traditional approaches in that it purposefully actualizes the integration of constructive and mathematical thinking into one holistic tool – professional competence based on a system-organizing cognitive factor – interpretive and innovative thinking and the use of digital technologies.

The "Constructive-interpretive concept of the development of mathematical knowledge and thinking of a future engineer" is developed in the system of the competency paradigm, which is aimed at the selective and targeted integration of knowledge, thinking, practices, and experiences into a holistic tool of professional activity. Accordingly, this pedagogical system is considered

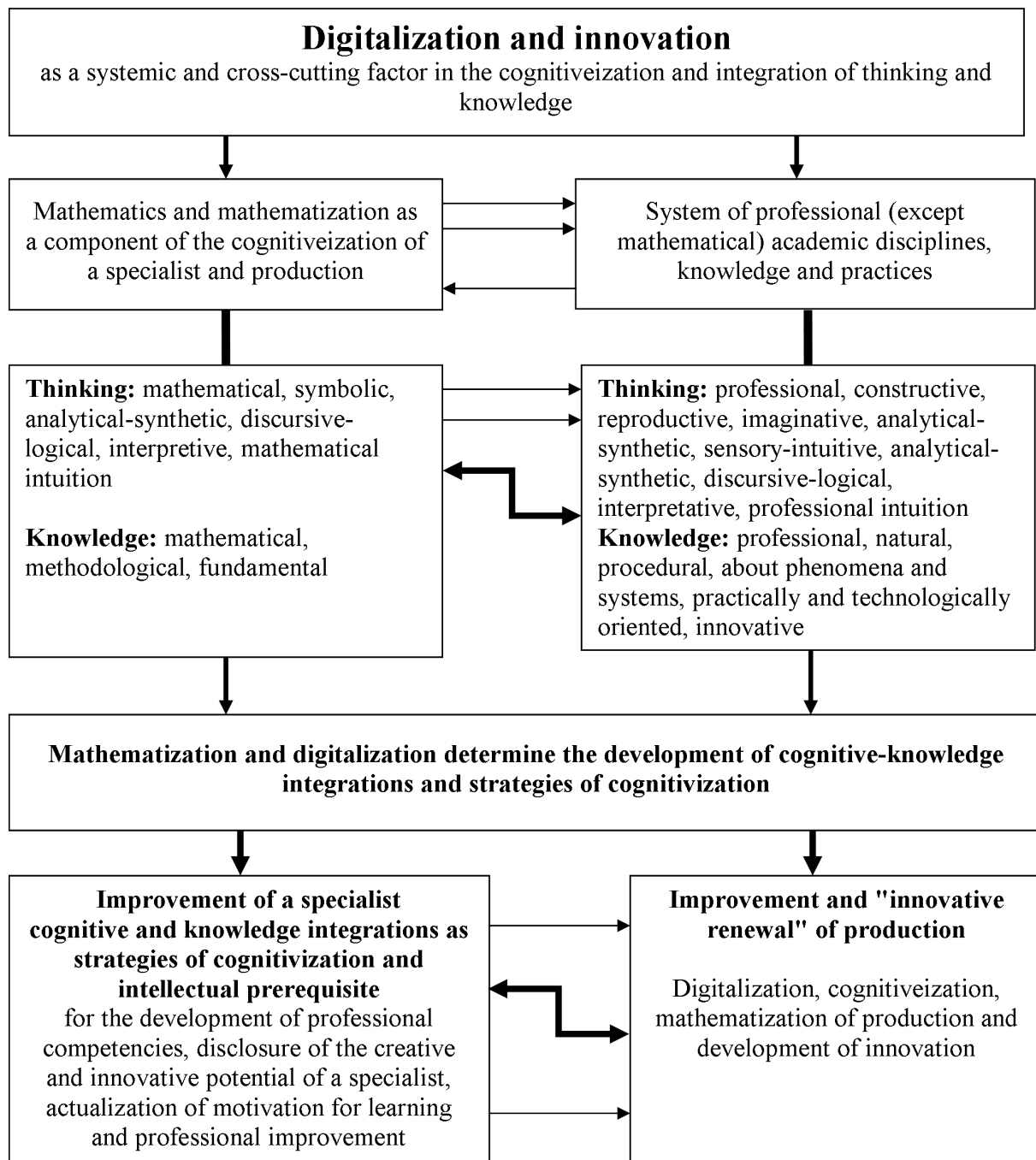


Figure 1. Development of cognitive-knowledge integrations as a defining intellectual strategy in the constructive-interpretive concept of the development of mathematical knowledge and thinking of a future engineer.

one of the options for professionalization, cognitivation and scientificization of both a specialist and production, which is implemented through the integrative application of mathematization and digital technologies. An additional effect of the above-mentioned “cognitive-knowledge integrations” (figure 1) is the actualization of the creative potential of the individual and the growth of motivation for learning and professional activity, which is implemented through active

innovative and interpretatively oriented “immersion” in professional practices based on the use of digital technologies.

Let us present the practical application of integrative operationalization and technologization of mathematical phenomena using the example of the Fourier series. The application of the Fourier series in engineering practices reveals the significant technological and cognitive potential of this mathematical phenomenon. In combination with digital technologies, the Fourier series is considered an effective intellectual and technological toolkit.

With this application of Fourier series, a spectrum of significant cognitive-constructive potentials of this mathematical phenomenon is revealed, among which the following are relevant for the cognitiveization and digitalization of a specialist and production: *modeling* – construction of mathematical models of processes and objects; *computational* – calculation of technical and technological systems, processes, objects; *interpretative-constructive* – changing the parameters on the basis of which calculations and models are formed and, accordingly, the development of model systems with their subsequent analysis and selection; *constructive* – participation in the design of technical, techno biological, techno social, techno anthropological objects, processes; tuning and optimization of both models and technical and technological systems; *anticipatory (prognostic)* prediction of the behavior of systems, models, objects, processes; *cognitive-constructive* — in-depth study and modeling of technical, biological, social and other phenomena and systems for the purpose of their imitation, improvement of models, formation of technical and technological objects; *representative-cognitive* — the possibility of building various models, primarily visual, with a cognitive and constructive purpose; *analytical-synthetic* — as a cognitive and cognitive-digital research tool; *innovative* — as a cognitive strategy and intellectual-digital tool for developing innovative products; *conceptualizing* — as an intellectual tool for conceptualization in the professional activities of a specialist; *descriptive* — as a cognitive and mathematical tool for describing and creating models of objects and processes; *methodologizing and scientification* — as an intellectual tool for developing a specialist’s methodological thinking and as a component of his scientific potential, as well as a mathematical-intellectual condition for the scientification of the organization and production.

To this purpose, an approach is proposed to adapt the traditional section of the Fourier series to the level and needs of engineering specialists. On the one hand, the presentation of the theoretical constructions of the Fourier series and integral is simplified. On the other hand, an attempt is made to prove the statement of the position using numerical methods and, thereby, to show students that the application of computational mathematics methods gives the Fourier series and integral an interdisciplinary character. And sets the goal of the advanced mathematics course as the formation of both general mathematical culture and mathematical reasoning skills for the effective application of numerical methods. To achieve this goal, the proposed learning technology provides a diverse set of animated tasks for performing calculations, which is not typical for existing classical textbooks on mathematical analysis. Many tasks for performing calculations has the following goals: first, to apply and consolidate important skills from the course of mathematical analysis, and secondly, through specific visual presentation of the results of calculations, it is easier for the student to master abstract constructions of the Fourier series and integral. In the developed task database, a prominent place is occupied by calculation tasks that involve the use of computer mathematics systems (CMS).

When studying the Fourier series, an object from a special section of advanced mathematics, as a new object, visualization is always desirable when perceiving it [10]. First, it helps to form an adequate image of a new concept. Visual perception allows you to directly see many properties and a visual representation of theorems that follow from the definition. Second, since the content of the image includes the main features of a class of objects, the demonstration of objects that belong to this class is especially important. Third, mathematical language is symbolic, but when not symbols are perceived, but their content, which, in fact, is reflected in

the imagination, then it is used similarly to the language of communication.

For example, students are invited to implement a visual mathematical model. At the same time, the student is required to find a solution using previously learned material (calculate Fourier coefficients by integration or apply CMS) according to a sample or template according to the specified sequence of actions.

At the initial stage, the student only uses a visual tool (a graph on a plane or in space, animation, etc.). The task is set to justify, prove, or choose the optimal variant of the method, model.

In another situation, the visual tool includes a task to solve a specific problem using a known general method, but through independent perception of the conditions of the problem, the solution result is predicted only in general form (a known program on CMS (for example, Maple [11]), it is necessary to apply double Fourier series).

The next technological step is to create a new one from known elements, based on the emergence of new connections between the elements of the new structure. For example, the Fourier transform is a tool for spectral analysis of non-periodic (pulse) signals. Such signals are different from zero only in a limited time interval. Students explore the features of these objects, in particular, the difference in the spectral density of a non-periodic signal from the discrete spectrum of a periodic signal.

An important technological step in the use of visual aids to activate students' creative abilities is independent activity when solving tasks that involve search and research activities in the process of implementing their ideas. Performing these tasks develops the skills acquired in previous technological steps and forms their own objectively new mathematical knowledge. For example, previously, double Fourier series were used to solve a hyperbolic partial differential equation, and a new problem may be related to an elliptic equation, which requires problem formulation and search.

For elliptic equations with constant coefficients, the solution is written in explicit form, and for equations with variable coefficients, the solution of systems of linear equations is used to find the solution. The Fourier coefficients in the system of quasi spectral polynomials of the first kind are divided into two groups: boundary and internal. The boundary coefficients are found exclusively from the boundary conditions, regardless of the elliptic equations, and the internal coefficients are found from the differential equation itself. The apparatus of quasi spectral polynomials can be widely used to solve initial-boundary value problems for differential equations [12].

Thus, learning schemes focused exclusively on the literal coverage of topics from the textbook or paraphrasing slides do not provide students with the opportunity to understand the content of the task, to creatively apply engineering principles in design. Such a "technical" concern is observed among students during their design course in the last year, which is proposed to use only engineering software for calculations, and not to apply mathematical methods to obtain results. In this case, such a problem can be solved by presenting visually presented objects during lectures and practical classes in the first year, when actions with function graphs are considered. For example, in the process of constructing harmonics, it is possible to show a graph of distorted harmonics in the production process and, thus, it improves the understanding of the need to apply fundamental mathematical concepts. In particular, visual applications were created: membrane oscillation models, alternating current distortion, and others. The uniqueness of such physical models lies in the implementation of a real-time monitoring system that allows students to visualize the behavior of the models and correlate theoretical concepts with their possible applications. As a result, students master the requirements/calculation procedures, and think in terms of design, study/research potential sources of malfunctions, and cost reduction factors.

Fourier series are an important means of approximating a periodic waveform in electronics and electrical circuits. For modern technology and engineering, it is important to be able to

use orthonormal systems, which decompose periodic signals into trigonometric series in terms of sines and cosines.

Let us consider an example that is given to a student to understand the behavior of partial sums of a Fourier series. It is used when students have acquired prior knowledge of the Fourier series. Therefore, the graphs of partial sums $S_n(x)$ when $n \rightarrow \infty$ in the vicinity of the breakpoint can fluctuate with a fairly large amplitude. This behavior of the Fourier series leads to errors in their application if the Fourier coefficients do not decrease faster than $n - 3$. In order to suppress such disturbances, “data windows” are used.

Figure 2 shows the process of synthesizing a periodic signal $F(t)$ from rectangular pulses by the partial sum of the Fourier series $S_n(t)$ (formula (1)). The figure 2 clearly shows the emergence of the Gibbs effect, wave-like oscillations at the peaks and troughs of the pulses.

$$S_n(t) = 0.5 \cdot \sum_{k=1}^n \frac{2}{(2k-1)\pi} \cdot \sin \frac{(2k-1)t}{2\pi}. \quad (1)$$

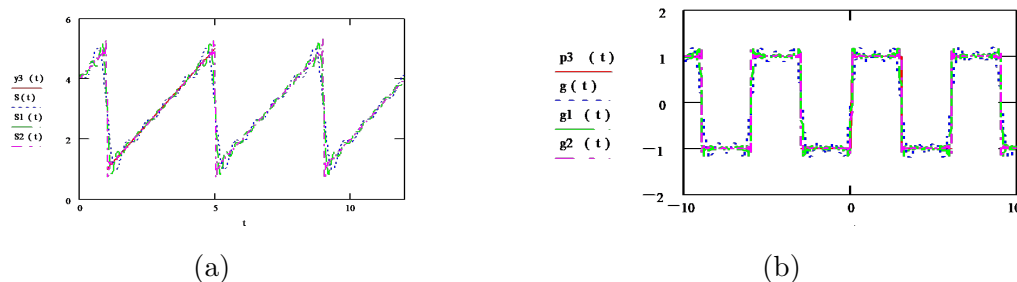


Figure 2. Development of the function $f(t) = \text{sign} \sin(t)$ into a Fourier series and approximation of the signal by partial sums $S_5(t)$, $S_{10}(t)$, $S_{20}(t)$ of the Fourier series: (a) – signal graph 1; (b) – signal graph 2.

The figure 2 illustrates the Gibbs phenomenon, regarding the approximation of the function $f(t) = \text{sign} \sin(t)$ by partial sums of the Fourier series $S_n(t) = \sum_{k=1}^n b_k \sin(k, t)$ for $n = 5, 10, 20$. The figures show that in the vicinity of the breakpoint, the deviation of the sums $S_n(t)$ is relatively significant (especially, $S_5(t)$) and reaches 18%.

Students should independently construct graphs of such sums $\sigma_n = \frac{1}{n} \sum_{k=1}^n S_k$ and draw a conclusion.

In particular, students are convinced that in the vicinity of the points of continuity of the function $f(x)$ the absolute value of the difference between the values of the function and the partial sum $S_n(x)$ tends to zero when $n \rightarrow \infty$ $|f(x) - S_n(x)| \rightarrow 0$. In addition, the rate of approach to zero at points x distant from the point of discontinuity is greater the farther x is from the point of discontinuity.

Students who, in their future professional activities, will deal with linear stationary processes that can be described by linear differential equations are offered to study methods for solving these equations by Fourier methods, in particular, the Fourier transform. In many cases, it saves time in the process of solving the problem. This approach is called the fast Fourier transform, which is based on dividing the curve by many uniformly selected points and is determined by the formula (2).

$$F(\omega) = \frac{1}{\sqrt{2\pi}} \cdot \int_{-\infty}^{+\infty} f(x)e^{-i\omega t} dx. \quad (2)$$

The student can be given an example that shows the direct and inverse Fourier transform. Figure 3a shows an example of a graphical representation of a signal, figure 3b shows the Fourier transform by means of the inverse transform, a signal graph (figure 3c) is obtained, similar to the graph in figure 3a. However, there may be cases when the obtained inverse Fourier transform needs to be corrected.

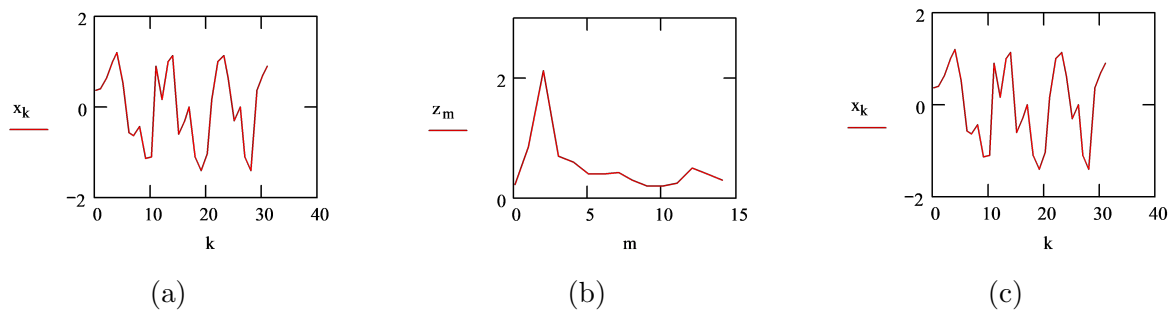


Figure 3. Graphical representation of: signal $f(t)$ – (a); its Fourier transform or spectral function of a continuous signal $f(t)$ – (b); inverse Fourier transform – (c).

The theory of the Fourier series is a component of methods for solving differential equations, both ordinary and partial derivatives of the second order – that branch of mathematics that has wide and diverse applications in mechanics, physics, and engineering. So, in particular, the Fourier method, or the method of separation of variables, is one of the most common methods for solving equations with partial derivatives, in certain situations, it is a natural and powerful tool for the effective representation of functions. The problems of mathematical physics where the Fourier method is used include the following: the problem of oscillations of a string fixed at the ends, free oscillations of a rectangular membrane, oscillations of a circular membrane, heat distribution in a rod, and others.

Let us consider an example of the application of a double Fourier series in an advanced mathematics course to solving the problem of oscillation of a rectangular membrane (figure 4).

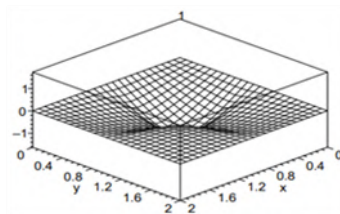


Figure 4. Image of the membrane at the moment when deflections decrease and become equal to zero, after which the membrane begins to bend downward.

Let the membrane at rest have the shape of a rectangle, which is bounded by the lines $x = 0$, $x = l$, $y = 0$, $y = m$.

The problem of membrane oscillations is reduced to solving the equation $\frac{\delta^2 u}{\delta t^2} = a^2(\frac{\delta^2 u}{\delta x^2} + \frac{\delta^2 u}{\delta y^2})$ with initial conditions $u|_{t=0} = f(x, y)$, $\frac{\delta u}{\delta t}|_{t=0} = F(x, y)$ and boundary conditions given on the boundary of the rectangle, $u|_{x=0} = 0$, $u|_{x=l} = 0$, $u|_{y=0} = 0$, $u|_{y=m} = 0$. We will solve the problem using the Fourier method. We are looking for a solution to the equation that satisfies the boundary conditions in the form of a product of three functions, each of which depends on only one argument (formula (3)).

$$u(x, y, t) = X(x)Y(y)T(t). \quad (3)$$

We are looking for a solution in the form of a series consisting of partial solutions. Each partial solution depends on two indices k and n , so the solution is formed in the form of a double sum (formula (4)):

$$u(x, y, t) = \sum_{k=1}^{\infty} \sum_{n=1}^{\infty} a_{k,n} \cos \omega_{k,n} t + b_{k,n} \sin \omega_{k,n} t \sin \frac{k\pi x}{l} \sin \frac{n\pi y}{m}. \quad (4)$$

The coefficients of the series are calculated similarly to the Fourier formulas (formula (5), (6)):

$$a_{k,n} = \frac{4}{lm} \int_0^l \int_0^m F(x, y) \sin \frac{k\pi x}{l} \sin \frac{n\pi y}{m} dx dy, \quad (5)$$

$$b_{k,n} = \frac{4}{lm\omega_{k,n}} \int_0^l \int_0^m F(x, y) \sin \frac{k\pi x}{l} \sin \frac{n\pi y}{m} dx dy. \quad (6)$$

By substituting the expressions for the coefficients $a_{k,n}$ (formula (5)) and $b_{k,n}$ (formula (6)) in a row (formula (5)), we complete the solution of the problem.

Next, a function is formed that characterizes the membrane's natural oscillations, we obtain the function $u_{k,n}(x, y, t)$, which satisfies the equation and boundary conditions. Each pair of positive numbers k and n corresponds to the function (formula (7)):

$$u_{k,n}(x, y, t) = (a_{k,n} \cos \omega_{k,n} t + b_{k,n} \sin \omega_{k,n} t) \sin \lambda_k x \sin \mu_n y. \quad (7)$$

In the following, we explain to students what stationary (standing) waves of a rectangular membrane are.

Now let's return to the problem of finding a solution that satisfies the initial conditions. As usual, we will look for it in the form of a series consisting of partial solutions. Each partial solution depends on two indices: k and n , so a double sum is formed. The functions $u_{k,n}(x, y, t)$ will describe the membrane's natural oscillations. Each of them is a stationary wave for a rectangular membrane, they can be represented in the form (formula (8)):

$$u_{k,n}(x, y, t) = F_{k,n} \sin(\omega_{k,n} t + \varphi_{k,n}) \sin \lambda_k x \sin \mu_n y. \quad (8)$$

It is clearly seen that each point (x, y) of the membrane performs a simple harmonic oscillation with frequency $\omega_{k,n}$ and amplitude $F_{k,n} \sin \lambda_k x \sin \mu_n y$.

All points pass through the equilibrium position at the same time, which are determined by the equalities $\omega_{k,n} t + \varphi_{k,n} = r\pi$, where r takes the value $0, 1, 2, 3, \dots$. In exactly the same way, the points simultaneously reach the maximum deviation.

For greater clarity, let us first consider the simplest oscillation, which corresponds to the case $k = n = 1$.

When the membrane oscillates, its contour remains stationary. Since in the middle of the rectangle $0 < x < l$ and $0 < y < m$, the functions $\sin \frac{\pi x}{l}$ and $\sin \frac{\pi y}{m}$ are positive and all points of the membrane are simultaneously located either on one side of the plane xOy , or on the other (depending on the sign of $\sin(\omega_{1,1}t + \varphi_{1,1})$).

The point with the greatest amplitude of oscillations will have a point for which $\sin \frac{\pi x}{l} = 1$ and $\sin \frac{\pi y}{m} = 1$, etc. The point with coordinates $(\frac{l}{2}, \frac{m}{2})$ is the center of the membrane.

It should be noted that 3D graphics are implemented in CMS systems, using which the above-mentioned tasks can be solved. In particular, the developed software procedure in CMS Maple provided the opportunity to perform dynamic visualization of the above mathematical physics task – the membrane oscillation problem.

In the section on Fourier series, the main attention is also paid to the problems of approximating a function by a partial sum of a Fourier series in a trigonometric or one of the polynomial systems: in orthogonal polynomials of Adrien-Marie Legendre, Charles Hermite, etc. Again, with implementation in one of the mathematical packages. Problems aimed at numerical implementation of solutions contribute to the formation of applied components of learning, increase student motivation, and contribute to the direct mastery of the main mathematical packages.

In practice, the Walsh function is used with different ordering methods. In general, they are the same for the spectral decomposition of signals. However, for some specific signals, the spectrum by the functions of one system may converge faster than the spectrum by the functions of other systems. Therefore, the advantage of one or another system may be revealed during the decomposition of specific signals with the subsequent use of truncated series.

Walsh functions on discrete intervals take the value ± 1 , which eliminates the effect of multiplication when calculating coefficients. The use of spectral analysis by Walsh reduces time costs, especially when using fast Walsh transform algorithms (according to the fast Fourier transform, figure 3). Compared with spectral analysis, the costs of machine time by harmonic functions are reduced by almost two times or more.

We offer students to consider the main features of the spectral representation of signals in the Walsh function base, in particular, signals given on the interval $[0, T]$. To decompose such signals, it is convenient to use Walsh functions orthogonal to the interval $[0, 1]$, which, after transforming their argument, are written in the form $wali(\frac{t}{T})$.

The Walsh series of a one-dimensional signal $x(t)$, $t \in [0, T]$ will look like

$$x(t) = \sum_{i=0}^{\infty} c_i wali\left(\frac{t}{T}\right),$$

where

$$c_i = \frac{1}{T} \int_0^T x(t) wali\left(\frac{t}{T}\right) dt.$$

Partial sums of the Walsh series

$$S(t) = \sum_{i=0}^{N-1} c_i wali\left(\frac{t}{T}\right)$$

it has uniform, mean-square convergence, and convergence on average and can be used to approximate signals described by integrated functions.

As noted above, in practice, Walsh functions are used with different ordering methods. From a general point of view, for spectral decomposition of signals, they are equal. However, the spectrum of one system may converge faster than the spectrum according to the functions of

other systems. Therefore, the advantage of one or another system may be manifested in the spectral decomposition of specific signals with the subsequent use of partial sums.

As noted, the work practices methods for increasing the level of activation of students' abilities using visual means. Thus, students are offered to implement a visual mathematical model of the decomposition of specific signals (harmonic function) using the Walsh function. To achieve a satisfactory approximation of a sinusoidal oscillation in the Walsh basis, students significantly increase the number of spectral components. Further increase in components is implemented using CMS by using partial sums. In this case, the student is required to find a solution using previously learned information (calculate Walsh coefficients by integrating or applying CMS) according to a sample or template according to the specified sequence of actions.

With the addition of mixing distortions, when the additions are provided by a limited number of Walsh functions, it is advisable to limit the ordering, which ensures a monotonic decrease of the spectrum. Such orderings when representing a segment of a sinusoid are the Paley, Hadamard, and Walsh subordinations, however, this construction does not depend on the way the functions are ordered. For example, to improve the approximation of a sinusoidal oscillation in the Walsh basis (figure 5) it is necessary to increase the number of spectral components.

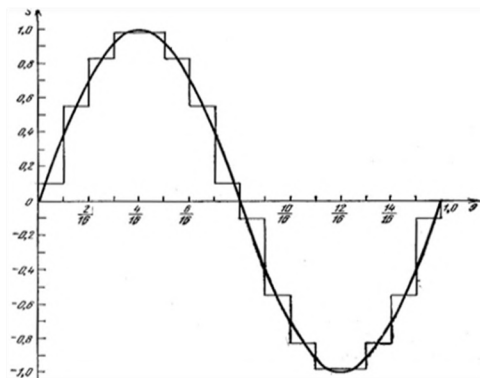


Figure 5. Recovery of the original signal using inverse Walsh transform functions. For a satisfactory approximation of a sinusoidal oscillation in the Walsh basis, it is necessary to significantly increase the number of spectral components.

There are many different orthogonal and orthonormal function systems, for example, the Rademacher function system, the Walsh function system, Legendre polynomials, Jacobi polynomials, and others, which students will familiarize themselves with in the additional literature. The choice of a particular system of orthogonal functions for the Fourier series expansion of the function $f(x)$ depends on the process described by the function $f(x)$. For example, in the theory of telecommunications, radio engineering, and electrical engineering, signals play an important role. For the study of signals using series, the most common orthogonal function systems are trigonometric function systems.

In the practice of calculations and research, polynomials that are solutions to the Legendre differential equation are often used (formula (9)).

$$(1 - x^2) \frac{d^2 y}{dx^2} - 2x \frac{dy}{dx} + n(n + 1)y = 0, \quad (9)$$

where $y(x)$ is a function of the variable x , and n is a non-negative integer that determines the degree of the Legendre polynomial. This equation is a special case of a more general class of differential equations that arise in problems related to spherical symmetry and has a solution in the form of Legendre polynomials.

The partial solutions of the Legendre equation are the Legendre polynomials $P_n(x)$. They are defined by the Rodrigues' formula (formula (10)).

$$P_n(x) = \frac{1}{2^n \cdot n!} \cdot \frac{d^n(1-x^2)^n}{dx^n}, n = 0, 1, 2, \dots \quad (10)$$

Students are given the task: using CMS MathCAD [13], prove that the system of functions

$$\varphi_n(x) = \sqrt{\frac{2n+1}{2}} \cdot P_n(x),$$

is orthonormal on the interval $[-1; 1]$. Since not every version of the MathCAD system fully implements the symbolic function, we can at least verify the orthogonality of some functions, for example, for $n = 1, 2, 3, \dots$.

The Fourier-Legendre series has the form

$$f(t) = c_1 P_1(t) + c_2 P_2(t) + c_3 P_3(t) + \dots + c_n P_n(t) + \dots,$$

where

$$c_k = \frac{2k+1}{2} \int_{-1}^1 f(t) P_k(t) dt.$$

We offer students an example for consideration: Expand into a Fourier series and a Fourier-Legendre series a function given on the interval $[-1; 1]$ by the relation:

$$f(x) = \begin{cases} 1, & -1 \leq x < 0; \\ 0.5 & x = 0; \\ x & 0 < x \leq 1. \end{cases}$$

Figure 6 shows the graphs of the first five terms of the Fourier series ($g(x)$) and the first six terms of the Fourier-Legendre series ($h(x)$) and the graph of $f(x)$ of the given function. At the point of discontinuity, the Gibbs phenomenon is weakly manifest. Analysis of the figure allows us to make a preliminary conclusion that partial sums with the same number of terms of the trigonometric series approximate the function more accurately than the corresponding partial sums of a series constructed using a system of orthogonal polynomials. Students obtain some estimates of the deviation of the approximate values of the partial sums of the Fourier series from the values of the function during modeling with other partial sums. Using animations, they will compare the numerical estimates and visual behavior of the partial sums of the series.

The pedagogical research was conducted in the conditions of a real educational process, in conditions familiar to students. A range of issues related to the effectiveness of the methodology for teaching series and integrals to students of higher education institutions and its impact on the development of students' creative abilities were experimentally investigated. During the experiment, experimental and control groups were distinguished. In the experimental groups, professionally directed teaching of Fourier series and integrals was carried out using modern CMS, in the control groups – according to the traditionally formed methodological system.

At the first stage of the study, mainly theoretical search methods were used: related to the analysis of literature and real pedagogical processes; students' creative abilities were assessed (the ability to establish and use analogy, perform comparison, analysis and synthesis, and classification) by analyzing questionnaires.

Analysis of the results of the ascertaining experiment allowed us to draw the following conclusions: that almost all junior and senior students are familiar with the techniques of creative

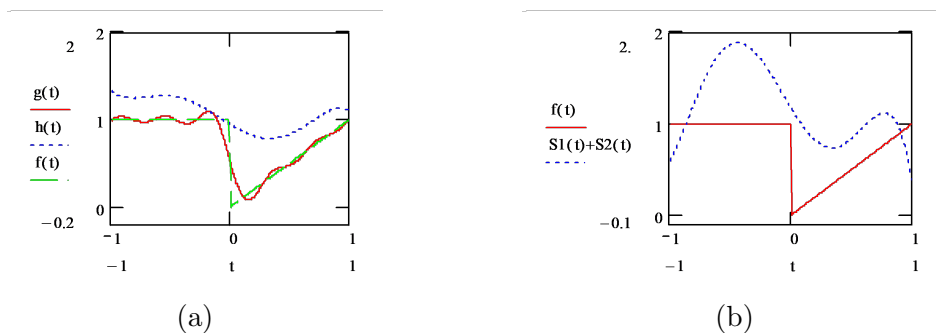


Figure 6. Graphs of the approximation of a function by the first terms of partial sums of the trigonometric Fourier series (a) and the Fourier-Legendre series (b).

thinking, but the level of formation of students' creative thinking is not high; about the presence of difficulties in solving problems of applied content and, especially, professionally oriented ones; it was established that there is a noticeable gap between theoretical knowledge and the ability to use them in practice.

At the second stage of the study, during the exploratory experiment, the research hypothesis was specified, and assumptions were formulated regarding the possibility of changing the existing approach to teaching advanced mathematics, taking into account the development of creative, professionally significant qualities of students, the professional direction in the training of students, and the conditions for conducting classes. With the help of applied tasks, the educational and research activities of students were modeled, colloquia and testing were conducted, which gave each student the opportunity to demonstrate their abilities, which allowed the most rational and effective achievement of learning goals.

During the experiments, it was noted that in the process of studying basic knowledge of Fourier series and integrals in all directions, almost all students were characterized by an inflated self-esteem. This is explained by the fact that students had not yet developed criteria, the application of which would allow them to objectively analyze their activities, and there were also no standards for comparison. The teacher's help in identifying errors and collective analysis of the results of the activity allowed by the end of the semester to bring self-esteem to a more or less objective level, although it remains somewhat inflated. This clearly indicates the effectiveness of the method of forming analysis skills and a critical approach to the analysis of activity in students.

Thus, the initial level of knowledge and skills in using CMS during visual modeling using series and Fourier transforms was established. At this stage, the issues of teaching methodology for individual questions of the series and Fourier transforms focused on the development of creative abilities of students of technical specialties were studied, the results of control works and student questionnaires were analyzed, the proposed technological system was discussed with university scientists and teachers, which allowed us to determine the main aspects of the research problem.

The analysis of the results of the search experiment allowed us to draw the following conclusions:

- increasing the efficiency of teaching special sections of the advanced mathematics course (for example, Fourier series and integrals) is facilitated by the diversification of organizational forms of teaching, and, in particular, the technology we have proposed using the visual CMS toolkit, as well as student participation in such forms as conferences, development by individual student teams of projects for creating electronic textbooks, etc.;
- elements of the technology for teaching mathematics in higher education institutions using

visual modeling, intensively saturated with professional professionally oriented content of tasks, have been developed;

- familiarization with the elements of computer modeling during the study of the topic of Fourier series and integrals, the application of CMS such as MathCAD to solving problems is advisable to carry out during the study of other special sections of the advanced mathematics course.

The formative experiment was carried out in the conditions of a real educational process and was aimed at revealing the effectiveness of the proposed methodological system, namely:

- clarifying the impact of studying special sections of the advanced mathematics course on the development of professionally oriented creative abilities of students, on the level of formation of their personal orientation;
- experimental verification of intensively saturated with professionally oriented content of educational tasks (consistency of theoretical material and relevant practical tasks and visual content, accessibility and logical presentation, sufficiency or redundancy of the material, identification of the level of interest in them by students).

During the first stage of the experiment, the dynamics of the growth of the level of formation of basic knowledge and skills of students in advanced mathematics and the development of the professionally oriented creative potential of students were traced.

In the process of forming the structure of subject concepts, the main activity of students was search activity, the component and result of which is the ability to construct Fourier series of the function $f(t)$ with their various structures, amplitude, and phase spectra of signals, and to estimate using CMS the approximation of a signal by partial sums of a Fourier series (figure 7).

The results indicate that the use of professional tasks in teaching mathematics increases the effectiveness of the formation of components of students' mathematical culture, the level of development of their creative abilities. The levels of development of creative abilities in the process of completing tasks were assessed using the criteria: 1) originality, 2) curiosity, 3) intuition, 4) comparison, 5) stability of attention, 6) communicativeness.

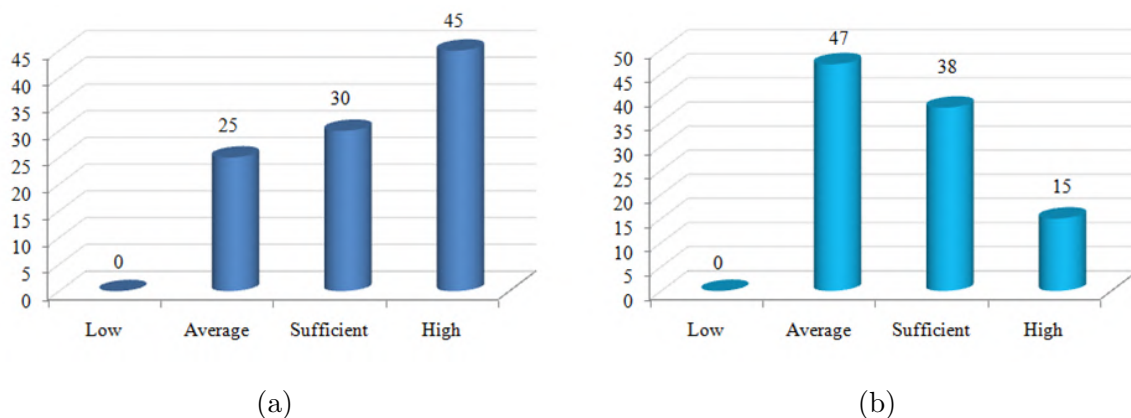


Figure 7. Comparison of the levels of development of future engineers' mathematical competencies and skills in mastering the visual CMS tools after conducting a formative experiment (%): experimental group (a); control group (b).

Thus, as a result of the implementation of the developed content and methodological techniques of teaching mathematics in experimental activities, a trend of positive changes in the levels of formation of special competencies in mathematics of future engineers was revealed.

The results of the experimental data in the study showed that when using the proposed technologies and techniques, the indicators of a high level of formation of mathematical and special competencies are three times higher than with the traditional approach. As a result of generalizing one's own experience, it was concluded that the teacher, when teaching Fourier series and integrals using the visual tools of CMS and constructing information electronic educational resources based on a communicative activity approach, develops universal educational actions of students.

It can be argued that the level of formation of individual components of creative abilities increased in students in both the control and experimental groups. Students developed creative thinking in the process of learning mathematics, namely: flexibility, speed, originality, accuracy of thinking when solving mathematical problems; spatial imagination; interest in mathematics; speed of data retrieval from the student's memory; ability to quickly move to new content areas; creative attitude to the profession, etc.

In addition to the analysis of qualitative characteristics, we will conduct an analysis using statistical methods of quantitative characteristics of the components of students' creative abilities. For this purpose, two-factor tables of features were constructed based on the performance of final control works and taking into account the results of exams (table 1).

Table 1. Results of assessing the development of students' creativity components (the frequency of the symptom).

Groups	After the experiment			Before the experiment		
	Presence of a symptom	Absence of a symptom	Total	Presence of a symptom	Absence of a symptom	Total
Experimental	18	7	25	14	11	25
Control	8	14	22	12	10	22
Total	26	21	47	26	21	47

According to the results of the final control, which included the performance of tasks from the proposed system and other elements of the Fourier series learning technology, we will test the statistical hypothesis H_0 about the absence of significant differences in the indicators of the quality of knowledge of students in the control and experimental groups.

We will use Fisher's angular transformation. The experimental data meet the requirements of the Fisher angular transformation: 1) there are no zero frequencies; 2) both samples contain more than 5 observations, which ensures the correctness of the comparisons.

Using the formula $\varphi = 2 \arcsin \sqrt{P}$ (where P is the percentage), we calculate the values of the angles for each of the groups: $\varphi(18/25 = 0.72) = 2.026$, $\varphi(8/22 = 0.36) = 1.294$. Thus, the empirical value is

$$\varphi_{emp} = (2.026 - 1.294) \sqrt{\frac{25 \cdot 22}{25 + 22}} = 2.504.$$

The critical value of the criterion φ_{cr} for pedagogical research at the significance level $\rho \leq 0.05$ is $\varphi_{cr} = 1.64$, and $\rho \leq 0.01 - \varphi_{cr} = 2.31$. Since $\varphi_{emp} > \varphi_{cr}$ ($2.504 > 2.31$), then Hypothesis H_0 is rejected, and hypothesis H_1 is accepted that the proportion of students in whom the effect is found – the use of the proposed system of tasks and other elements of the Fourier series learning technology affects the development of creative abilities of future specialists.

It should be noted that before the start of the study, no daytime effect was observed, and the qualitative indicators of the groups were relatively homogeneous. That is, $\varphi(14/25 = 0.56) =$

1.692, $\varphi(12/22 = 0.54) = 1.65$. $\varphi_{emp} = (1.692 - 1.65)\sqrt{\frac{25 \cdot 22}{25+22}} = 0.144$. Since $\varphi_{emp} < \varphi_{cr}$ ($0.144 > 1.64$), then Hypothesis H_0 is accepted.

Thus, the students who studied using the developed technology for teaching Fourier series and integrals, focused on the development of creative abilities of students of technical specialties, has a higher level of development of creative abilities.

4. Conclusions

The effectiveness of the technology for forming the concept of Fourier series and integrals and their application based on the technology of visual modeling in the mathematical training of engineers in modern conditions of digital transformation of approaches to creating visual content and during the study of advanced mathematics has been experimentally confirmed.

The reliability of the results obtained was checked using the Fisher criterion. The obtained empirical values of the Fisher criterion exceed the critical value $V_{cr} = 2.31$ at the level of statistical significance $\alpha = 0.01$ in the experimental and control groups. Thus, the hypothesis of non-random changes in the levels of educational achievements in studying the concept of Fourier series and integrals and their application to solving applied problems is confirmed. It has been proven that this method of forming professionally oriented mathematical competencies using CMS is effective.

After analyzing the results of the experiment, it was determined that there are: positive learning dynamics aimed at the development of special mathematical knowledge and the formation of creative abilities, which is implemented by using Fourier series and integrals, computer visualization technologies in the educational process; students who studied using the developed technology for teaching Fourier series and integrals have a higher level of development of creative abilities.

Methodologically and conceptualizing knowledge in the training of future engineers is special knowledge about Fourier series, which is integrated with visualization and animation technologies and is presented as significant cognitive-knowledge and “visual-technological” factors in the formation of professional thinking.

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Conversion Factor Wheel: a tool to improve unit conversion skills in Grade 12 STEM students

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Conversion Factor Wheel: a tool to improve unit conversion skills in Grade 12 STEM students

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Abstract. This study explores the effectiveness of the Conversion Factor Wheel, an Android-based application designed to aid Grade 12 STEM students at Cantilan National High School in overcoming challenges with unit conversion. Unit conversion, a foundational skill in STEM education, is often a significant obstacle to student success. The Conversion Factor Wheel provides a visual and interactive approach to simplifying conversions of length, mass, volume, and time. Using an experimental design, the study assessed students' initial understanding through a pretest, implemented the app in classroom instruction, and evaluated its impact with a posttest. Results revealed a substantial improvement in students' performance, with mean scores increasing from 4.8 (48%) in the pretest to 9.45 (94.5%) in the posttest, reflecting a significant mean difference of 4.65. Additionally, students expressed high satisfaction with the app, as evidenced by a psychological validity rating of 74.13%, underscoring its acceptance and usability. The findings highlight the Conversion Factor Wheel's effectiveness as an innovative instructional tool for enhancing mastery of unit conversion. The study concludes that integrating the app into STEM education can positively impact learning outcomes and support students' academic growth. This app is highly valuable for CNHS students because it can be used remotely without an internet connection, giving it a significant advantage over other online-only tools.

1. Introduction

Unit conversion is the process of expressing a quantity in one set of units as an equivalent quantity in another set, typically within the same physical dimension. It involves multiplying the original quantity by a conversion factor that relates the two sets of units, enabling measurements to be understood and compared across different systems. In STEM (science, technology, engineering, and mathematics) education, mastering unit conversion is a foundational skill essential for analyzing and using quantitative data effectively. The Most Essential Learning Competencies (MELCs) for STEM, particularly STEM_GP12EU-Ia1 [1], highlight its importance in solving measurement problems and expressing measurements in scientific notation.

Despite its significance, unit conversion poses challenges for many senior high school students, negatively affecting their performance in STEM subjects. Research has shown that difficulties with metric unit conversion persist even among college-level students [2] and prospective science teachers [3]. For example, a study in the United States revealed that many students struggled with unit conversion in introductory college science courses, even after prior exposure [2].



Similarly, another study found that prospective science teachers exhibited significant gaps in understanding metric unit conversions [3]. Recent research also demonstrated that task-based interventions can enhance students' skills, highlighting the potential for innovative teaching tools to address these challenges [4].

At Cantilan National High School, Grade 12 STEM students often struggle with unit conversions involving lengths, weights, volumes, and time. These challenges hinder their ability to solve real-world problems that require accurate conversions. To address this issue, the researchers developed the Conversion Factor Wheel, a mobile application designed to enhance students' unit conversion competency. This tool provides an interactive and user-friendly interface, making unit conversion operations more accessible and engaging. By simplifying complex operations, the app aims to improve students' understanding and performance in STEM subjects.

This study seeks to evaluate the effectiveness of the Conversion Factor Wheel in addressing unit conversion challenges faced by Grade 12 STEM students at Cantilan National High School. Additionally, it aims to contribute to the existing body of knowledge on instructional strategies for unit conversion, offering valuable insights for educators and curriculum developers to enhance STEM education.

2. Methodology

2.1. Development of the tool

The Conversion Factor Wheel application was developed as a user-friendly mobile tool to aid in unit conversion tasks involving length, mass, volume, and time. The app featured an intuitive interface where students could input values and instantly receive equivalent measurements in various units. The app is especially important for CNHS students as it functions offline, providing a major advantage over other tools that require an internet connection.

2.2. Research design

This study utilized an experimental research design with pre-test and post-test assessments to evaluate the effectiveness of the Conversion Factor Wheel in enhancing unit conversion skills. The design was chosen to compare students' performance before and after using the tool, enabling a systematic examination of its educational impact. The study focused on Grade 12 STEM students enrolled in science and mathematics subjects involving unit conversion at Cantilan National High School.

2.3. Participants and sampling

The participants were randomly selected from two sections of Grade 12 STEM students at Cantilan National High School. The total population of these students was 48, with 23 in one section and 25 in the other. A sample size of 20 students, representing approximately 42% of the population, was used in the study. Random selection was employed to ensure heterogeneity and minimize selection bias, with students from both sections participating. While the sample size does not constitute 50% or more of the total population, it was considered acceptable given the naturally small population size in the school. The researchers acknowledge this as a limitation and recommend further studies with larger samples to enhance the generalizability of findings.

2.4. Data collection

To establish a baseline, a pre-test consisting of multiple-choice questions and problem-solving tasks on unit conversions was administered. After the intervention period, during which the Conversion Factor Wheel was utilized, an identical post-test was administered to measure improvement. Additionally, a questionnaire was distributed to collect qualitative data on students' experiences with the tool, focusing on usability, satisfaction, and cognitive load.

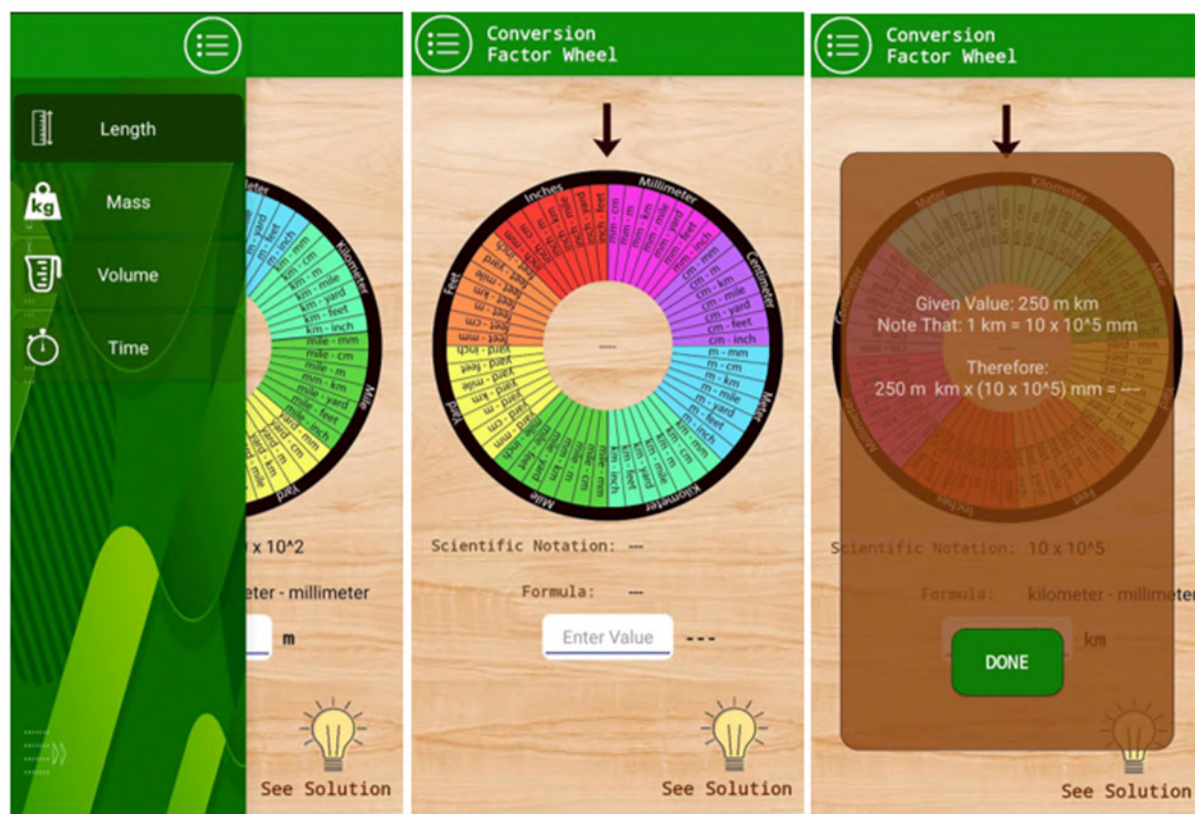


Figure 1. The Conversion Factor Wheel.

2.5. Data analysis

Quantitative data from the pre-test and post-test were analyzed using statistical measures, including mean, standard deviation, and a paired t-test, to assess the significance of score improvements. The significance level was set at $p = 0.05$. Qualitative data from the questionnaires were analyzed using thematic analysis to identify common themes related to the tool's usability and effectiveness. The use of both quantitative and qualitative data strengthened the study's validity and provided a comprehensive evaluation of the Conversion Factor Wheel's impact.

3. Results and discussion

In table 1, the implementation of the Conversion Factor Wheel led to a notable improvement in students' unit conversion skills. Initially, the pretest mean score was 4.8 out of 10 (48%), indicating a Not Proficient level. After the intervention, the posttest mean score increased to 9.45 out of 10 (94.5%), reflecting a Highly Proficient level. This significant enhancement suggests that the instructional material effectively addressed the students' initial challenges in unit conversion. Similar studies have demonstrated that targeted instructional tools can substantially improve students' understanding of unit conversions. For instance, a study on the use of a Smart Conversion Card Tool reported positive impacts on students' perceptions and understanding of unit conversions [5]. Additionally, research on the effect of conversion factors on problem-solving abilities found that such methods enhance students' success in problem-solving tasks [6].

Based on table 2, the paired t-test analysis indicates a significant improvement in students'

Table 1. Pretest and posttest scores with proficiency levels of students using the Conversion Factor Wheel.

Student	Highest possible score	Pre-test			Post-test		
		Actual score	Percentage	Level of proficiency	Actual score	Percentage	Level of proficiency
1	10	3	30%	Not Proficient	8	80%	Proficient
2	10	5	50%	Nearly Proficient	9	90%	Highly Proficient
3	10	4	40%	Not Proficient	9	90%	Highly Proficient
4	10	5	50%	Nearly Proficient	10	100%	Highly Proficient
5	10	5	50%	Nearly Proficient	9	90%	Highly Proficient
6	10	5	50%	Nearly Proficient	10	100%	Highly Proficient
7	10	5	50%	Nearly Proficient	9	90%	Highly Proficient
8	10	6	60%	Nearly Proficient	10	100%	Highly Proficient
9	10	6	60%	Nearly Proficient	10	100%	Highly Proficient
10	10	4	40%	Not Proficient	9	90%	Highly Proficient
11	10	4	40%	Not Proficient	9	90%	Highly Proficient
12	10	6	60%	Nearly Proficient	10	100%	Highly Proficient
13	10	6	60%	Nearly Proficient	10	100%	Highly Proficient
14	10	7	70%	Nearly Proficient	10	100%	Highly Proficient
15	10	3	30%	Not Proficient	8	80%	Proficient
16	10	4	40%	Not Proficient	10	100%	Highly Proficient
17	10	6	60%	Nearly Proficient	10	100%	Highly Proficient
18	10	4	40%	Not Proficient	9	90%	Highly Proficient
19	10	4	40%	Not Proficient	10	100%	Highly Proficient
20	10	4	40%	Not Proficient	10	100%	Highly Proficient
Mean score	10	4.8	48%	Not Proficient	9.45	94.5%	Highly Proficient

Legend:

- 90%–100% - Highly Proficient
- 71%–89% - Proficient
- 50%–70% - Nearly Proficient
- 0%–49% - Not Proficient

performance between the pre-test and post-test scores, with a mean difference of 4.65 and a t-value of 35.418 at 19 degrees of freedom. The standard deviation of 0.587 and standard error of 0.131 suggest consistent improvements across the group. The 95% confidence interval of the difference, ranging from 4.375 to 4.925, further confirms the reliability of the observed improvement. These results highlight the effectiveness of the instructional intervention in enhancing students' understanding of the competency. Active learning strategies are emphasized for their significant role in achieving substantial enhancements in students' mean achievement scores [7], which supports the findings of this study. This study also aligns with recent studies that highlight the efficacy of structured and interactive teaching tools in promoting learning gains and student achievement [8].

Table 3 reveals a significant mean difference of 4.65, with a t-value of 35.418, leading to the rejection of the null hypothesis. This finding indicates a meaningful improvement in students' problem-solving skills post-intervention. This aligns with [9] who highlighted the positive impact

Table 2. Descriptive statistics of pre-test and post-test scores.

	Mean	Standard deviation	Standard error	95% confidence interval of difference		t-value	DF
				Lower bound	Upper bound		
Pre-test Score - Post-test Score	4.650	0.587	0.131	4.375	4.925	35.418	19

Table 3. Paired t-test results comparing pre-test and post-test scores and its statistical significance.

	Mean difference	t-value	Decision	Interpretation
Pre-test Score - Post-test Score	4.650	35.418	Ho rejected	Significant

of visual aids on students' academic performance in secondary education.

Table 4 presents the psychological validity of the Conversion Factor Wheel app based on student feedback across five questionnaires: perceived usefulness, perceived ease of use, satisfaction, engagement, and cognitive load. Each questionnaire includes specific questions, with total scores, weighted means, and verbal descriptions provided for each. The overall mean score is 74.13%, with a weighted mean of 3.70, described as "Good". This comprehensive evaluation highlights the app's strengths and areas for improvement, supporting its effectiveness in enhancing students' problem-solving skills.

Table 5 presents the summarized data from five psychological validity questionnaires: perceived usefulness, perceived ease of use, satisfaction, engagement, and cognitive load. Each questionnaire is evaluated with total scores, weighted means, and verbal descriptions. The total scores range from 64.33% to 79.30%, with corresponding weighted means from 3.21 to 3.96. All verbal descriptions are labelled as "Good", indicating a positive perception of the Conversion Factor Wheel app across all dimensions. The overall mean score for all questionnaires is 74.13%, with a weighted mean of 3.70, also described as "Good". This comprehensive evaluation underscores the app's effectiveness in engaging students and enhancing their problem-solving skills [10].

In summary, all the students' responses were all good, indicating a high satisfaction rating with the use of the Conversion Factor Wheel. All the twenty (20) respondents agreed that the app helped in solving conversion problems more efficiently and they agreed the recommendation of the Conversion Factor Wheel app to others, making a hundred percent and a verbal description of excellent.

4. Conclusion and recommendations

This study demonstrated that the Conversion Factor Wheel is an effective instructional tool for enhancing unit conversion skills among Grade 12 STEM students at Cantilan National High School. The significant increase in post-test scores, coupled with the students' high satisfaction rating of 74.13%, underscores the tool's positive impact on student learning. The findings suggest that the Conversion Factor Wheel not only improved students' performance but also addressed their challenges in mastering unit conversions, making it a valuable resource for STEM education.

To maximize its potential, the Conversion Factor Wheel should be implemented as a regular

Table 4. Students' psychological validity of the Conversion Wheel.

Questionnaire items	Total score	Weighted mean	Verbal description
Questionnaire 1: perceived usefulness			
1.1. How useful do you find the Conversion Wheel app in your activity?	78	3.9	Good
1.2. Does the app help you solve conversion problems more efficiently?	80	4.0	Excellent
1.3. Would you recommend the Conversion Wheel app to others?	80	4.0	Excellent
Questionnaire 2: perceived ease of use			
2.1. How easy is it for you to navigate the Conversion Wheel app?	75	3.75	Good
2.2. Do you find the app's interface intuitive and user-friendly?	80	4.0	Excellent
2.3. How quickly were you able to learn how to use the Conversion Wheel app?	71	3.55	Good
Questionnaire 3: satisfaction			
3.1. How satisfied are you with the overall performance of the Conversion Wheel app?	80	4.0	Excellent
3.2. Are you happy with the accuracy of the conversions provided by the app?	80	4.0	Excellent
3.3. Do you think the Conversion Wheel app meets your expectations?	76	3.8	Good
Questionnaire 4: engagement			
4.1. How often do you use the Conversion Wheel app?	60	3.0	Good
4.2. Do you find the app engaging and interesting to use?	79	3.95	Good
4.3. Would you like to see more features added to the Conversion Wheel app?	80	4.0	Excellent
Questionnaire 5: cognitive load			
5.1. How mentally demanding do you find using the Conversion Wheel app?	60	3.0	Good
5.2. Does the app require a lot of your attention and concentration?	75	3.75	Good
5.3. Do you feel overwhelmed or confused when using the Conversion Wheel app?	58	2.9	Fair
Mean score	74.13%	3.70	Good

Legend:

- 90%–100% - Highly Proficient
- 71%–89% - Proficient
- 50%–70% - Nearly Proficient
- 0%–49% - Not Proficient

Table 5. Summary of psychological validity questionnaires.

Psychological validity questionnaires	Total scores (%)	Weighted mean	Verbal description
Questionnaire 1: perceived usefulness	79.30%	3.96	Good
Questionnaire 2: perceived ease of use	75.33%	3.76	Good
Questionnaire 3: satisfaction	78.66%	3.93	Good
Questionnaire 4: engagement	73.00%	3.65	Good
Questionnaire 5: cognitive load	64.33%	3.21	Good
Mean score	74.13%	3.70	Good

Legend:

- 90%–100% - Highly Proficient
- 71%–89% - Proficient
- 50%–70% - Nearly Proficient
- 0%–49% - Not Proficient

instructional tool in senior high school STEM classes, with proper teacher guidance. Future studies should examine its long-term effects on students' academic performance to assess its sustained impact. Second, compare it to traditional methods and other digital methods existing. Extend its application to other grade levels and academic tracks. Additionally, integrating the Conversion Wheel into teacher training programs and national STEM curriculum guidelines is recommended to promote innovative instructional practices. Finally, further refinements to the tool could focus on stimulating critical thinking and providing personalized feedback for learners and identify any problems associated with the app.

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Fostering early understanding of vaporization in 5-6-year-olds via engineering design

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Abstract. The current paper presents the results of a qualitative study focusing on children's mental representations of the vaporization (boiling and evaporation) of water. The study involved 19 preschool children (mean age: 5.05 years), and the research design included pre- and post-tests to record children's mental representations, along with a structured teaching process that followed the four stages of the Engineering Design Process. The research data showed that most children of this age were able to adequately approach vaporization, meaning that the initial mental representations of the children could be transformed into representations compatible with school scientific knowledge. Finally, the results of the study lead to the conclusion that children of this age are capable of constructing a precursor model for steam, boiling, and evaporation, that is, vaporization.

1. Introduction

The study of mental representations formed in children's minds about natural phenomena and scientific concepts has been a significant focus of research in various fields, such as Cognitive Psychology and Science Education. Although this research initially targeted older students who attend structured science lessons, in recent decades, it has also addressed the development of children aged 3 to 8. Indeed, as the holistic development of children evolved from a general principle of Preschool Pedagogy into a research activity, part of this research turned towards exploring children's understanding of the natural world. This research gradually expanded to include various aspects of early childhood science education, such as curricula [1,2], educators [3,4], and instructional strategies [5–7]. In all these research orientations, the great importance given to mental representations is evident, as they often act as the basis for programs construction, teachers training and teaching activities development. However, identifying [8,9] and transforming [10–12] young children's mental representations into entities compatible with school scientific knowledge remains a crucial research direction. Indeed, both the identification of comprehension difficulties and the conscious effort of school to address them and lead children's thinking to reasoning compatible with school scientific knowledge is the main purpose of the early introduction of young children to the natural sciences. A series of studies employing specialized teaching interventions aimed at overcoming obstacles created by mental representations have shown that young children can “construct mental entities about natural phenomena compatible with certain characteristics and functions of school scientific knowledge, such as describing and



predicting phenomena. These entities, which demonstrate stability across different contexts and employ consistent criteria for reasoning, are referred to as ‘precursor models’ and have been systematically researched in recent years” [13, p. 2]. For example, studies on children’s mental representations have led to the development and implementation of teaching interventions that resulted in precursor models for floating and sinking [14,15], variations within populations [16], among others. The research presented here describes a teaching intervention aimed at constructing a precursor model for the phenomenon of vaporization in children aged 5-6 years.

Thermal phenomena, which are part of daily experiences and sources of curiosity for children, have been extensively studied in Early Childhood Science Education (ECSE). Research on how children aged 3-8 approach thermal phenomena often focuses on state changes in matter, particularly water transformations. These studies may take a broader perspective on the water cycle in nature [17,18] or focus on specific phase changes, such as condensation [19] or melting [20,21]. Despite differences in research topics, a recurring finding is the ‘prelogical’ nature of children’s thinking, indicating reasoning patterns that do not align with school scientific knowledge [22].

Part of this research focuses on children’s understanding of water vaporization. Although familiar to children, this phenomenon has complexities since it occurs through both boiling and evaporation, and its connection to thermal exchanges between bodies or systems is not always apparent. Research on children’s understanding of vaporization follows two directions: (a) identifying the mental representations children use to reason about the phenomenon and (b) investigating the outcomes of specially designed teaching activities. Some studies in the second category include an initial stage of recording children’s mental representations.

- (a) In a study with children aged 6-8, most children faced significant difficulties understanding evaporation and could not explain it when observed [23]. Another study with children aged 4-7 revealed that most children struggled to describe the transformation of a liquid to another state of matter, with only two-thirds recognizing the conservation of water [24]. Other studies have found that even children who acknowledge water conservation after vaporization do not understand its transition to the gaseous state, instead searching for the water on surfaces or furniture [25–27]. Additionally, systematic analysis of children’s mental representations regarding vaporization showed that approximately nine out of ten children aged 5-6 could not predict what would happen if a small amount of water were strongly heated. When observing an experiment, they focused on specific features, such as bubbles or steam, without explaining where the water went [28].
- (b) In the same study [28], a teaching intervention was designed to address these obstacles. During a natural experiment on water vaporization, using related cards to visualize the process, focusing on the movement of bubbles and steam helped approximately eight out of ten children to form a satisfactory reasoning scheme about vaporization. In another study utilizing the theoretical framework of embodied learning, activities were designed for children aged 5-6 to explore water during an environmental theme. After examining evaporation in various contexts, children expressed the upward movement of water vapor using their bodies, indicating a satisfactory understanding of evaporation [29]. Another study designed activities for children of the same age to construct a precursor model for all aspects of the water cycle in nature [30]. Among these phenomena was evaporation, approached through a simple teaching process where children made predictions, observed, and discussed the observable sequence of events: “bubbles-steam-decrease in water level-increase in vapor quantity-movement of vapor into the air”. The data showed that two-thirds of the children, who initially could not understand evaporation, developed a stable precursor model. Another study with students aged 6-9 approached evaporation understanding through a unique instructional methodology using a narrative with intentional errors [31]. In this narrative, children could reach a satisfactory description

of evaporation by identifying mistakes. Data analysis showed that half of the students not only approached evaporation satisfactorily but also understood that cloud formation results from evaporation.

The research presented here focused on the phenomenon of water evaporation. In the first phase, young children's mental representations regarding the transition from liquid to gas were investigated, followed by a second phase aimed at transforming these representations through a designed teaching process intended to construct a precursor model for vaporization. Key elements of such a model include recognizing the thermal nature of vaporization with or without boiling in familiar phenomena. Therefore, two research questions were formulated to record possible changes in children's reasoning between the pre-test and post-test.

The first research question investigated children's mental representations about evaporation with or without boiling when they are directly asked about the phenomena.

The second research question explored children's mental representations of vaporization in everyday life situations.

2. Methodological framework

2.1. Participants

The study involved 19 children with an average age of 5.05 years (9 boys and 10 girls). All children attended a kindergarten class in Piraeus, Greece. The sample was convenient, and participation was voluntary. No activities related to vaporization had been conducted in this class before. The research team obtained ethics approval from the Department of Educational Sciences and Early Childhood Education at the University of Patras (approval No. 11, March 21, 2023).

The research was conducted by an experienced educator.

2.2. The research process

The research was conducted in three phases (figure 1). In the first phase, individual interviews were conducted to record children's mental representations that posed difficulties (pre-test). A week later, in the second phase, a teaching intervention took place where children participated in a group process based on the Engineering Design Process (EDP) for Early Childhood Science Education [32]. This phase involved a cycle of activities at four levels: (1) Problem, (2) Inquiry, (3) Designing and Testing, and (4) Conclusions and Presentation. The third phase occurred a week after the second phase, where post-test individual interviews were conducted to record any changes in children's mental representations.

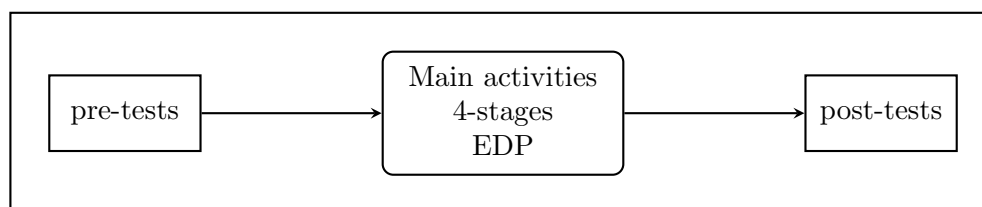


Figure 1. Research process.

2.3. Questions in the pre- and post-test

To study children's mental representations of evaporation and boiling, eight questions were used, with questions 1-3 corresponding to the first research question and questions 4-7 to the second. These questions formed the basis for discussions with the children to clearly capture the reasoning prompted by their mental representations. The questions are presented below:

- (i) Do you know what steam is? Have you seen it? Where?
- (ii) Have you heard the word “evaporation” before? Where? What is it? Why does it happen?
- (iii) Have you heard the word “boiling” before? Where? What is it? Why does it happen?
- (iv) Have you ever gotten your clothes wet? What did you do then? (Did they dry? How?)
- (v) If we put a glass of water in the yard under the sun, what would happen?
- (vi) The sea is exposed to the sun every day. What happens then?
- (vii) What will happen if we boil water? Will the amount of water before and after boiling be the same? Why? Why not?

2.4. The teaching intervention

After analyzing the pre-test data, during the “Problem” stage of the Engineering Design Process, a story was presented to the children, introducing two problematic situations: (a) Little Argyris lives in a village near the sea. While playing by the water, a wave suddenly soaked him! His shirt was wet! What will Argyris do now? (b) Argyris was sitting on his balcony on a sunny day, filling a glass of water to drink. Suddenly, Eirini called him to play, and he left without drinking the water. When he returned, the glass seemed strange... (why?). The children were asked to identify and describe the problems and explain why solving them was important.

In the second stage, “Inquiry”, the researcher facilitated a discussion based on the children’s familiarity with drying clothes in the sun, noting their ideas on a whiteboard and encouraging them to make predictions and propose solutions to Argyris’ problem. The children made predictions and proposed solutions, trying to understand where the water goes when clothes dry or what happens to the water in a glass left outside.

In the third stage, “Designing and Testing”, the children individually designed their proposed solutions for drying clothes. Subsequently, experimental situations were conducted collectively, including: (a) soaking a piece of clothing and hanging it to dry inside the classroom, observing it at intervals, (b) placing a glass of water outdoors in the schoolyard in a sunny spot in the morning, (c) heating and boiling water using a portable burner. The children observed the experiments and discussed their outcomes. Following this, the students participated in a movement-based game called “Liquid-Gas” / “Water-Steam.” The children initially moved within a designated space with their hands joined, simulating liquid water. They then transitioned to moving freely around the space, representing steam or gas. The activity aimed to correlate the children’s movements with the stages of boiling. Additionally, a group discussion took place to explore whether seawater or lake water boils or evaporates under natural conditions.

In the fourth stage, “Conclusions and Presentation”, the children collaborated to create a poster that addressed the following questions: (a) How will Argyris’s shirt dry? How did we discover where the water from the glass went? (b) When does this happen? (c) Why does this happen? The boiled water was not exposed to the sun, but something else caused it to boil – what was it?

After completing their collaborative poster, the children took turns presenting it individually and documenting their presentations using a portable device. One child assumed the role of presenter, while another took on the role of videographer.

2.5. Data analysis

2.5.1. The pre- and post-test. The children’s interviews were audio-recorded and transcribed, and the analysis was conducted using the transcriptions. The children’s responses were classified into three distinct categories: (a) sufficient, (b) intermediate, and (c) insufficient. Sufficient responses were those compatible with qualitative, macroscopic school knowledge about water evaporation and boiling across different phenomena. That is, answers that were described with the appropriate variables and correctly predicted the changes related to evaporation.

Intermediate responses included correct predictions about evaporation without linking them to thermal phenomena, or vice versa. Finally, insufficient responses were those that did not describe evaporation using appropriate variables and did not adequately predict changes related to evaporation, meaning they were unrelated to school scientific knowledge.

Both before and after the teaching intervention, the analysis of the children's responses and their classification into the three categories were conducted by two researchers, with an agreement rate exceeding 90%. In cases of disagreement, a third researcher was consulted.

2.5.2. The EDP analysis. During the implementation of the four stages of the Engineering Design Process (EDP), qualitative data were collected through: (a) audio recordings of the researcher's speech, the children's speech, and all dialogues (total duration: 1 hour and 50 minutes), (b) the children's drawings (19 drawings in total), (c) protocols on the children's non-verbal behavior, and (d) analysis of the video-recorded material. The data analysis was based on the transcribed texts, supported by all other materials. The texts were divided into episodes based on content related to boiling and evaporation [33–35]. The analysis of these episodes aimed to identify the critical points where necessary cognitive transformations occurred in children's thinking, leading to the formation of key elements of the precursor model.

3. Results

3.1. The pre- and post-test

This section presents characteristic responses of the children across the different categories for the seven interview questions (1-3 addressing the first research question and 4-7 addressing the second) in the pre- and post-test.

Question 1. Do you know what steam is? Have you seen it? Where?

The responses to this question fell into three categories:

- (a) Sufficient responses: Children were able to describe what steam is, where they had seen it, and connect it to thermal phenomena such as boiling. For example: "It's water" (S19), "It's the air coming out of my mom's pot when she cooks" (S1), "It's water boiling" (S6), and "It gives off steam from above" (S9), "It's smoke that comes from water turning into vapor" (S11).
- (b) Intermediate responses: Children described their experiences with steam but did not connect it to any thermal phenomena. For example: "I saw it in a cigarette" (S14), "It's gray smoke" (S5), "The extractor fan pulls it in" (S15).
- (c) Insufficient responses: Children could not describe steam or gave irrelevant answers. For example: "Steam is a machine that shoots fire" (S6).

Question 2. Have you heard the word "evaporation" before? Where? What is it? Why does it happen?

The responses to this question also fell into three categories:

- (a) Sufficient responses: Children described the phenomenon of evaporation, mentioning factors such as a heat source and water. For example: "It turns into smoke (the water) from the sun because the sun is very hot and can make it smoke" (S11), "Because it's really hot, the water goes up and turns into smoke" (S14).
- (b) Intermediate responses: Children described their experience with evaporation, focusing on the outcome without mentioning the conditions for evaporation, such as a heat source. For example: "It becomes smoke" (S7) or "Steam because it gives off a lot of air" (S9).

- (c) Insufficient responses: Children could not describe evaporation, connected it with other phenomena, or were unable to provide any answer. For example: “When you start the engine and step on the gas, the exhaust emits smoke” (S3).

Question 3. Have you heard the word “boiling” before? Where? What is it? Why does it happen?

The responses to this question fell into three categories:

- (a) Sufficient responses: Children described the phenomenon of boiling, mentioning factors such as a heat source and water. For example: “We put water, turn on the stove for 10 minutes, and the water moves” (S6), “It produces bubbles and the water heats up” (S13), “Like steam... we need to turn on the stove to heat it up” (S5).
- (b) Intermediate responses: Children described their experience with boiling, focusing mainly on the water temperature. For example: “It boils in the pot, it gets hotter” (S7), “We boil the food, it gets hot” (S4).
- (c) Insufficient responses: Children could not describe the phenomenon of boiling, gave incorrect answers, or were unable to provide any response. For example: “The water melts” (S5).

Question 4. Have you ever gotten your clothes wet? What did you do then? (Did they dry? How?)

The responses to this question fell into three categories:

- (a) Sufficient responses: Children could explain how they could dry a wet shirt and that exposure to heat causes drying. For example: “I’d go out in the sun to dry my shirt because it’s very hot, and it would evaporate, meaning it would dry” (S14), “Dry a shirt with a hairdryer” or “In the sun because the heat makes the water go away” (S7).
- (b) Intermediate responses: Children could predict how a wet shirt might dry but did not explain why or gave explanations without mentioning thermal phenomena. For example: “Dry it in the yard where there’s sun; the water goes to the sun” (S5) or “With a hairdryer or leave it outside for a while in the sun; the water will melt and won’t be wet anymore because it will fall down” (S17).
- (c) Insufficient responses: Children could not provide any answer to the question.

Question 5. If we put a glass of water in the yard under the sun, what would happen?

In this question, we identify three categories of responses:

- (a) Sufficient responses, where children appear to be able to predict what might happen if a glass of water is exposed to the sun, and reference the phenomenon of evaporation. For example: “The glass will get very hot, the water will heat up because there is a lot of sun, and it will heat up and evaporate, meaning the water will disappear and there will be nothing left” (S1), and “Some of the water would have evaporated, it turns into smoke” (S7).
- (b) Intermediate responses, where children are able to predict what would happen if a glass of water is left exposed to the sun, but they fail to link the process with any thermal phenomena or cannot explain their response in detail. For instance: “It will burn... it will go away” (S8), “The water will go lower” (S6), and “It will be less because it was heated by the sun” (S2).

- (c) Insufficient responses, where children fail to predict correctly what will happen during this process and are unable to provide a correct explanation. For example: “The water will turn yellow” (S4), or “The water will melt, then turn to ice, and then back to water; the rest will melt” (S5).

Question 6. The sea is exposed to the sun every day. What happens then?

In this question, we again identify three categories of responses:

- (a) Sufficient responses, where children are able to describe what happens when the sea is exposed to the sun and mention the phenomenon of evaporation. For example: “It’s hot and it also gives off smoke; it doesn’t empty” (S3), “The sun just sees it and it evaporates, when we wash our hands, it goes back and forms a cycle” (reference to the water cycle) (S14), “It releases steam, but it doesn’t release all the water” (S17).
- (b) Intermediate responses, where children describe what happens to the sea but do not mention the phenomenon of evaporation. For example: “Some water goes to the sky” (S18), or “Because it’s large, it doesn’t get smaller” (S13).
- (c) Insufficient responses, where children fail to predict correctly what will happen during this process and are unable to provide an appropriate explanation. For example: “It heats up, it empties because it has holes” (S9), or “The sun melts it, it’s dried up” (S5).

Question 7. What will happen if we boil water? Will the amount of water before and after boiling be the same? Why? Why not?

Lastly, in Question 7, we again identify three categories of responses:

- (a) Sufficient responses, where children were able to correctly answer about the amount of water after boiling, providing explanations based on the presence of steam, boiling, etc. For example: “It will form bubbles, some water will remain, and the rest will go into the air” (S9), “It will go down because the water boils and turns into steam” (S15).
- (b) Intermediate responses, where children correctly respond about the amount of water after boiling but do not provide explanations related to thermal phenomena. For example: “It will decrease because it’s under the sun” (S1), “It goes less, and you can see it, it goes to the sun” (S2), or “The water will decrease because it’s very hot” (S12).
- (c) Insufficient responses, where children are unable to answer correctly regarding the amount of water after boiling or provide no answer at all. For example: “A lot, up to the top” (S4), “It will change, it will grow because of all the water” (S6), or “It will stay the same” (S7).

Table 1 presents the frequency of responses to the seven questions. The children were numbered from 1 to 19. Additionally, since no gender differences were observed, the data are presented in aggregate form.

3.2. The four stages of EDP

3.2.1. First stage: problem In this stage, as we explained, a methodological choice was made to tell two short stories based on evaporation. This effort aimed to start the discussion of the phenomenon from potentially real situations in which children could recognize a common theme, that is, to move from a specific situation to a more abstract reasoning. It seems that this was achieved as many children identified the problem in both situations, and the dialogues that developed focused on the relationship between heating and evaporation. Below, we provide two characteristic examples of dialogues between the researcher and the children, which reflect a good approach to this relationship.

Table 1. Frequencies of pupils' responses

	Pre-test						Post-test					
	sufficient students	f	intermediate students	f	insufficient students	f	sufficient students	f	intermediate students	f	insufficient students	f
Question 1	1, 19	2	8, 14, 17	3	2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 15, 16, 18	14	1, 6, 7, 9, 11, 12, 14, 17, 18, 19	10	5, 8, 15	3	2, 3, 4, 10, 13, 16	6
Question 2	14	1		0	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11,12, 13, 15, 16, 17, 18, 19	18	8, 11, 13, 14, 19	5	7, 9, 18	3	1, 2, 3, 4, 5, 6, 10, 12, 15, 16, 17	11
Question 3	6, 14	2	1, 3, 7, 8, 9, 10, 11, 15, 16, 17,18	11	2, 4, 5, 12, 13, 19	6	1, 3, 5, 6, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19	15	2, 4, 7, 8	4		0
Question 4	6, 8, 12, 13, 14,15,16	7	1, 2, 3, 4, 5, 7, 9, 10, 11, 17, 18	11	19	1	2,3,4,6,7,8,12,13, 14,15,16,17	12	1, 5,9,10, 11,18,19	7		0
Question 5	1, 14	2	7	1	2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13, 15, 16, 17, 18, 19	16	1,3,4,5,7,10,11, 12,13,14,15,16, 17	12	2, 6, 8,9,15, 18,19	7		0
Question 6		0	14	1	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 18, 19	18	3, 14, 17	3	13, 18	2	1,2,4,5,6,7,8,9, 10, 11,12,15,16,19	14
Question 7	14	1		0	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 18, 19	18	3,5,7,8,9,11,13, 14,15,16,17,18, 19	19	1, 2, 4, 6, 10, 12	6		0

Researcher (R): When Argyris returned from the game, why did his glass look strange?

Student (S4): Because of the sun, it left...

R: And where did it go?

S14: It turned to smoke...

S13: Because the sun made it melt, it made the water hotter, and it left.

S4: It turned to smoke...

R: Why was the glass empty?

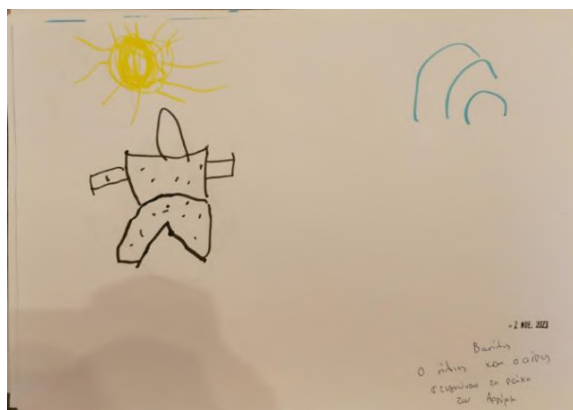
S14: It might have evaporated...

R: What does that mean?

S14: It means it turned into smoke because of the heat from the sun.

The two drawings in figure 2 depict the suggestions of two children on how Argyris' clothes will dry. In their explanations for both drawings, there is a clear reference to heating from the sun and the air.

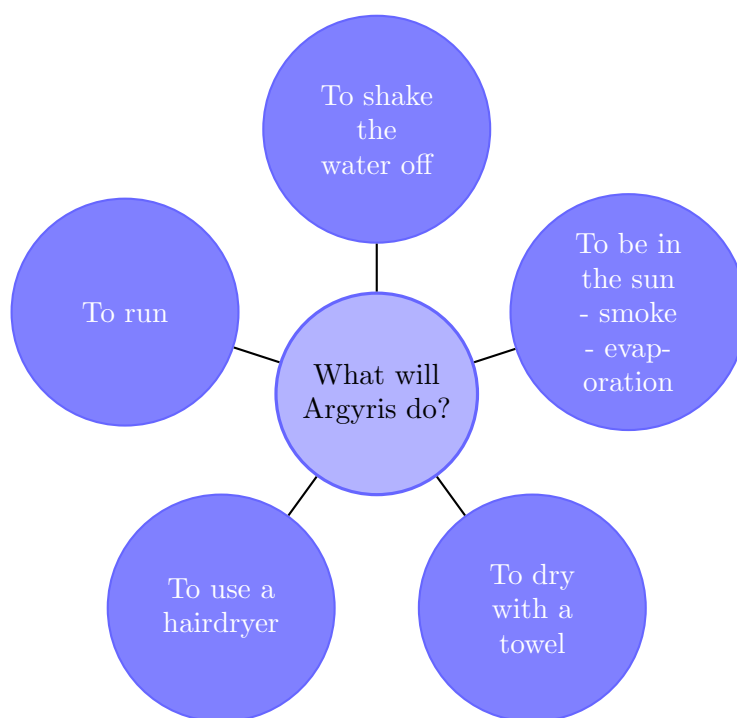
3.2.2. Second stage: inquiry In the second phase, the effort focuses on exploring the issue of evaporation with all the children. As the discussion develops among the children, the ideas they express for the two proposed situations are recorded on an interactive board, and the discussion gradually shifts towards the issue of water transitioning from the clothes and the glass to the air. From this recording, the concept map shown in figure 3 was created, depicting the actions that Argyris must take to dry his clothes.



S8: The sun and the air dry Argyris's clothes.



S13: Argyris, the sea, and the air with the sun to dry.

Figure 2. The clothes dry from the heating of the Sun and the air.**Figure 3.** Concept map for drying clothes

The children's discussions, supported by the researcher, gradually shift from invoking mechanical means, such as shaking or wiping with a towel, to relating to thermal means, such as the Sun or a hairdryer. Below, we provide some characteristic dialogue excerpts:

R: What can Argyris do?

S14: Go out in the Sun.

R: Why should he go to the Sun?

S14: The Sun will turn the water into smoke.

S13: He can use a hairdryer to heat his shirt.

R: Where did the water go (from the shirt)? Why don't we see it?

S16: It went to the Sun.

S6: It went to the Sun.

S18: It fell down.

S4: It went to the sea.

S17: It dried.

S11: It went down the drain.

S14: It evaporated.

R: So?

S14: The water turned into smoke and went up. The smoke disappeared because of the air.

R: But where did the water from the glass go?

S13: The water melted because of the Sun.

The expansion of these discussions gradually leads to boiling water, providing the opportunity to focus on this phenomenon as well. Below are some additional dialogue examples:

R: What happens when the water boils?

S18: There are bubbles.

R: Only?

S4: It has air.

S13: A kind of smoke... (The children imitate boiling with their bodies)

R: I boil a quantity of water and then turn off the stove... what will happen?

S14: A bit of water will evaporate because it will have turned into smoke with a lot of heat.

S13: It's possible that the smoke above the bubbles took this missing water.

S12: It went into the air.

3.2.3. Third stage: designing and testing As described in the methodology, the children were asked to design activities for drying clothes and then took part in a series of activities for boiling and evaporation.

Most children designed and chose to expose their wet clothes to the Sun or a hairdryer to heat and dry the clothes. One student even designed an enclosed space with lights that would shine on the clothes and dry them, as the lights would "look at the water and make it leave."

Then, during the activities, dynamic interactions helped the children process and stabilize their reasoning. Below are some dialogue examples from the three activities:

(a) Hanging a wet shirt to dry.

In the classroom, a shirt got wet and was hung on a line near a window facing the Sun.

R: What will happen now?

S16: It will dry.

R: Where will it dry faster?

S15: In the Sun.

S18: In the Sun.

R: Has the water in the shirt decreased? Where did it go?

S14: Into the air.

S17: It dried.

(b) A glass of water in the yard.

We left a glass of water outside in the yard on a sunny day for several hours. The children observed that the water level had dropped below the control line we had marked. In discussions with the children, it is interesting that they referred to steam or smoke for the evaporating water, even though evaporation is not visible, so the children reasoned based on an abstract mental entity.

R: What happened in this case?

S14: It turned into smoke.

R: How did this happen?

S14: Because it's really hot.

R: From where?

S18: From the Sun.

S12: From the Sun.

R: What is the name for what goes up?

S14: Steam.

(c) Boiling water

We placed a small amount of water in a heating device, and soon boiling occurred.

R: What will happen when it starts to boil?

S16: Bubbles.

S14: When the water starts to run out... it will turn into smoke.

R: If the water boils, what will happen to the amount of water?

S7: It will decrease.

R: Is it boiling?

S16: It's making bubbles.

S17: Smoke...

S16: Steam...

3.2.4. Fourth stage: conclusion and presentation In this stage, the children were asked to present the results of their work and conclusions to children from another class. After a participatory discussion in the plenary, they decided to create a group poster, as they were more familiar with this way of documenting and presenting. The children freely designed their poster featuring Argyris getting wet and hanging his clothes on the balcony, where the Sun can see them. They even drew small drops that gradually leave Argyris' clothes. Additionally, the children depicted the boiling condition, choosing to place a small kettle on a stove. They even decided to draw the water leaving in the form of drops (blue color) and the steam created (white color) (figure 4). Furthermore, the children individually presented their posters as presenters and recorded their presentations using a portable device.

In this stage, many children were able to explain how a wet shirt will dry and explain how they investigated the issue of the water that left from the glass exposed to the Sun. They could also answer when and why this happens. Analysis of the recorded material showed that the children described and presented their posters in a way that clearly reflected the influence of the activities they had previously engaged in, mentioning detailed information. For example, "a sun that heats the water, and the water goes away and becomes steam" (S14) or "a sun that heats the shirt, and these are drops that leave the shirt" (S13). Finally, regarding boiling, almost all the children could describe the existence of "a pot with steam" (S7) or "small drops" (S1).

4. Discussion

In this article, a qualitative study was presented, focusing on the possibility of transforming the mental representations of approximately 5-year-old children and constructing a precursor model



Figure 4. The children's group poster.

in their thinking regarding the evaporation, and boiling of water. In this research, with pre- and post-tests, the children's mental representations of the phenomena were recorded. Between the two tests, a structured teaching process was taken place based on an EDP (Engineering Design Process) framework in four distinct stages, compatible with the pedagogical framework of a kindergarten, yet fully aligned with the cognitive needs of the children.

The first research question was addressed with the first three interview questions. These questions aimed to capture whether and how children attribute meaning to the phenomena based on their everyday experiences. Additionally, in the post-test, it was investigated whether the children, after participating in the teaching process, could formulate stable reasoning based on fixed elements signaling the construction of a precursor model. As seen in table 1, while only 10% of children attributed meaning to the terms vapor, evaporation, and boiling in the pre-test, in the post-test, answers consistent with school scientific knowledge ranged from 26% to 79%. An interesting qualitative aspect of these results is that the children consistently attributed a thermal character to the phenomena they described.

The second research question was addressed with interview questions 4-7. Here, the goal was to assess whether children could interpret changes in specific everyday situations based on reasoning rooted in thermal exchanges. Before the teaching process, the percentages of correct answers compatible with school scientific knowledge ranged from 0% to 37%. However, in the post-test, these percentages changed to range from 16% to 100%. This change is significant, as it highlights that the teaching intervention was well-tailored to the cognitive needs of the children

and that they were able to reorganize their experiences.

The data from the pre- and post-tests are consistent with those from previous studies, as the difficulties encountered by the children, which have been documented elsewhere, are detected [23–27]. Furthermore, similar to an earlier corresponding attempt [28–31], they provide strong evidence that, regarding the issue of vaporization and the underlying phenomena of evaporation and boiling, a precursor model is beginning to form in their thinking, as the reasoning they present is stable and compatible with school scientific knowledge. It should also be noted that in the children’s “intermediate” answers, it is often apparent that they engage in reasoning based on thermal changes, though they do not express it clearly [36].

From the overall results, the possibility of transforming children’s intuitive mental representations of vaporization into other representations compatible with school scientific knowledge is highlighted. These new representations allowed children to make descriptions and predictions based on thermal exchanges, signaling the formation of a precursor model for vaporization. The effectiveness of the Engineering Design Process is important here, as in its four phases, a teaching intervention creates a favorable environment for building new knowledge. Indeed, the creation of small everyday-realistic problems and their immediate experimental confirmation creates the necessary conditions for overcoming children’s difficulties [37]. Simultaneously, the opportunity given to children to draw individually or in groups and present their work to other children – the transition from one mental representation to another – has been shown in the literature to facilitate model formation [38].

5. Study limitations

The current research was qualitative in nature and was conducted with a small number of children drawn exclusively from one kindergarten class. Undoubtedly, these factors constitute limitations of the study. It is evident that triangulating qualitative results with quantitative data collection from research using a quantitative or mixed-methods design would allow for determining the breadth and stability of the children’s new mental representations, and thus for confirming the formation of precursor models in the thinking of young children regarding vaporization.

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Computer modelling of atomic-molecular states leading to Maxwell distribution

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Abstract. This article examines the dynamics of transitioning from the traditional educational model focused on information accumulation to an innovative information model emphasizing the development and quality of research outcomes within smart educational environments. This approach facilitates the integration of computational resources with the cyber-physical nature of natural phenomena. We address the challenge of computer modelling atomic-molecular gas states subject to Maxwell distribution laws, employing an integrative method of simulated visual-dynamic computer modelling developed using Python's Matplotlib module. The resulting visualization, termed integrative presentation-dynamic computer visualization, enables the creation of Python programs that construct models of Maxwell's graphical simulated dynamic distribution. The adjustable parameters within these models provide new insights into the physical essence of molecular velocity distributions. Through this approach, students develop an autonomous worldview oriented toward independent truth-seeking and scientific inquiry.

1. Introduction

The Strategy for the Development of Higher Education in Ukraine for 2022-2032 [1], grounded in SWOT analysis of educational conditions, advocates for a paradigm shift from the traditional educational model of information accumulation to an innovative information-based computer model that prioritizes the development and quality of research outcomes within smart educational environments. This approach creates favorable conditions for integrating computational resources with the physical essence of natural phenomena through the transition from conventional information accumulation to sophisticated computer simulation. The result is a cyber-physical system wherein phenomenon development is monitored through computer programs and utilized by learners, thereby fostering an autonomous worldview oriented toward independent truth-seeking.

According to extensive research by Bondarenko et al. [2], Bykov [3], Lavrentieva et al. [4], Merzlykin et al. [5], Oliynyk et al. [6], Oleksiuk et al. [7], Sytnyk and Zinovieva [8], Vasyliuk et al. [9], Vlasenko et al. [10, 11], and Zelinska et al. [12], open modern educational ICT environments facilitate accelerated learning, enable efficient utilization of humanity's accumulated scientific and technological expertise, and support rapid information transfer between subjects. Building upon this foundation, we investigated the problem of computer modelling atomic and molecular gas states leading to Maxwell distribution using our developed



integrative method of simulation visual-dynamic computer modelling (IM SVD CM). This method employs Python's Matplotlib module to model the distribution of molecules, atoms, and ions by velocities. The resulting visualization, which we term integrative presentation-dynamic computer visualization, models gaseous, electronic, and similar phenomena with variable research parameters, thereby establishing an integrative information and communication smart environment [6]. This approach enables the omission of complex mathematical details while explaining distributions through modelling algorithms. The programming codes are straightforward to develop and implement, with results that align with theoretical expectations.

This visualization methodology requires precise definition of concepts characterized by fundamental variable parameters that remain independent of system dimensions, particularly in thermodynamic systems. While such systems are traditionally described through mathematical models – including well-established equations of gas state, diffusion principles, and thermodynamic laws – these models often leave undefined the concepts of absolute dynamic pressure, excess pressure, and atmospheric (barometric) pressure. Moreover, the essentially undefined concept of gas pressure, assumed uniform across all system points [13–15], requires clarification. In contrast to conventional approaches, integrative presentation and dynamic computer visualization enables students to perceive absolute pressure as the sum of barometric and manometric pressures: $P_{abs} = P_{atm} + P_{overl}$, or as the difference between barometric and vacuum pressures: $P_{abs} = P_{atm} - P_{vac}$.

The IM SVD CM we have developed enables simulation of Maxwell's ideal gas velocity distribution for analyzing these pressures and a comprehensive range of gas processes within an integrative information and communication smart environment. Traditional teaching methods in natural sciences and technical disciplines at higher education institutions (HEIs) have devoted insufficient attention to the characteristics of such environments [13], despite the demonstrated high effectiveness of ICT utilization [16]. For instance, when examining ideal gas pressure on vessel walls, the specific determination of pressure on the vessel bottom is typically not analyzed separately, although this can be readily explained through computer modelling (CM) [17].

The proposed IM SVD CM, combined with Python's Matplotlib module tools for Maxwell distribution, contributes to expanding students' research and project activities while intensifying learning through active ICT utilization [18–23]. This yields a novel content structure for teaching gas phenomena using open online resources, including: Udacity and Coursera platforms, EdX and Udemy online courses, MIT OpenCourseWare interactive courses, OpenL and FutureLearn platforms, Prometheus educational projects, LabXchange online educational content, Dingtalk, and other resources [19, 21, 24].

According to this pedagogical approach, the organization of students' educational activities encompasses three progressive stages: comprehension of theoretical foundations; development of practical competencies in creating computer programs (CP) and graphical velocity distribution interpretation; and deepening and consolidation of knowledge through application to atomic and molecular gas states.

2. Literature review

2.1. Classical studies on Maxwell's model

The transition of open education from information accumulation to an information model emphasizing development and quality outcomes has been extensively investigated by Bykov [3], Striuk et al. [25], and other researchers. The role of computer models in education has been examined by Khavrus and Shelevytsky [26], Kolgatin et al. [27], Soloviev et al. [28], Teplytskyi [29, 30], Tryfonova [31], and others.

The advancement of ICT has revitalized interest in studying ideal gas properties, originating from Maxwell's investigation of ideal gas molecule velocity distribution [32]. Maxwell synthesized the foundational work of D. Bernoulli (thermal molecular motion as the cause of pressure), J.

Herapath (dynamic theory of gases), J. P. Joule (mechanical equivalent of heat), A. K. Krönig (atomic gas composition with collision-based interactions causing wall pressure), R. Clausius (elastic ball molecular interactions), J. R. von Mayer (energy conservation law), C. F. Gauss (normal probability distribution), and others, concluding: “From the hypothesis that smaller matter particles undergo rapid motion with temperature-dependent velocity, numerous material properties, particularly in gaseous form, can be deduced, making the true nature of this motion a subject of natural interest” [32, p. 51]. Notably, these scientists employed both conceptual and mathematical models.

During the 20th century, the ideal gas concept gained fundamental significance and underwent extensive development across scientific, industrial, and educational domains. Mathematical modelling justification for this concept has been explored by Boltzmann [33], Kalinchak and Chernenko [34], Kikoin and Kikoin [14], Krobthong [16], Landau and Lifshitz [17], Rivadulla [35], Savelyev [15], Sivukhin [36], and others.

The complete disorder of molecular motion paradoxically enabled researchers to intuitively extract models of order from chaos. Maxwell’s mathematical model of molecular velocity distribution revealed a novel fundamental property of matter in instantaneous equilibrium – a property previously unknown. Maxwell approached the very boundaries of mechanical understanding of matter models and successfully transcended them [32].

2.2. Mathematical models of Maxwell distribution and computer modelling

Maxwell successfully subjected chaotic molecular gas motion to rigorous mathematical laws, thereby paving the way for computer modelling of these processes. Among the pioneering studies in computer simulation was the work by Ftáčnik et al. [37], who described a straightforward computer program simulating two-dimensional molecular collisions leading to Maxwell distribution. More recent research highlights computer modelling applications in molecular dynamics for studying silicon ablation under 266-nm femtosecond laser action [38], cellular signal communication between organisms using an event-driven molecular dynamics simulator created with the Omnet++ Simulation Framework [39], and nanoprocesses in plasma physics [40].

2.3. Applications of computer simulation in physics education

Computer modelling of physical processes represents a powerful pedagogical method that enhances learning effectiveness [16], develops students’ computational literacy [41], and demonstrates alternative approaches to studying physical phenomena [42].

The study by Krobthong [16] compared achievement levels among natural and technical field students enrolled in “Fundamentals of Physics” courses. Results demonstrated that the experimental group, taught using interactive scientific modelling methods, achieved significantly higher performance than the control group lacking such methods.

Computational essays have emerged as an effective modelling tool – a writing form combining text with compact programs, interactive diagrams, and computational tools to express ideas. This approach is well-integrated throughout the physics curriculum at the University of Oslo, Norway, where students’ computational essays are driven by Python code block outputs [41].

Rivadulla [35] presents an accessible simulation of gas molecule collisions for CP students, facilitating successful mastery of Maxwell distribution. Peqini and Osmanaj [42] performed Maxwell distribution simulations for multiple dimensionalities using MATLAB. These researchers recommend this approach as a demonstrative tool for lecture classes, enriching teaching quality and improving student comprehension.

Python and its modules have proven effective for creating computer simulations, as demonstrated in [22, 41, 43, 44].

2.4. Smart learning environments

Literature review reveals extensive opportunities and prospects for smart learning environment development. Rosmansyah et al. [45] define these as hybrid learning systems providing learners and stakeholders with engaging learning processes while achieving outcomes through intelligent tools and techniques. Chen et al. [46] argue that smart learning applies technological and social developments to facilitate effective personalized learning through innovative technologies. Dimitriadou and Lanitis [47] note that the term “smart classroom” has evolved to reflect technological advancements incorporated in educational spaces. Researchers further explore possibilities for integrating artificial intelligence and smart technologies in smart classrooms.

However, existing studies have not adequately addressed the potential for creating smart environments through Python programming, enabling detailed examination of concepts including chaotic gas particle motion, system equilibrium states, temperature, impulses, and vessel wall pressure based on contemporary understanding of molecular velocity distribution accounting for arithmetic mean, root mean square, and most probable velocities.

2.5. Study limitations

This study presents several limitations. First, physical limitations arise from describing ideal gas properties exclusively. Second, computer models were constructed solely using Matplotlib and Python, precluding generalization to other modelling environments. Third, the developed methodology’s implementation occurred only once; obtaining more reliable results would require repeated pedagogical experiments.

3. Methodology

We propose that these challenges can be successfully addressed through our developed integrative method of simulation visual-dynamic computer modelling of gas micro-processes, thereby creating presentation-dynamic graphic computer visualization and a qualitatively and quantitatively novel software integrative environment.

Within such environments, subject competence can be effectively developed through project and research activities, simulating cyber-physical phenomena that approach the authentic behavior of studied objects.

The article’s objectives are to: investigate the transition from educational models of information accumulation to information models emphasizing development and research quality improvement within smart environments; develop an integrative method of simulation visual-dynamic computer modelling for gas microprocesses, creating presentation-dynamic graphical computer visualization of molecular, atomic, ionic, electronic, and phonon gas velocity distributions using Python’s Matplotlib module; and provide novel interpretations and definitions of fundamental molecular physics and thermodynamics concepts.

The study employed the following methods: theoretical analysis of European and domestic scientific works to clarify conditions and essence of ideal gas molecule velocity distribution using computer modelling, self-assessment methodology to determine effective self-organization of educational/professional activities and establish dynamics in self-organization levels; empirical methods including programming language selection, educational process monitoring in HEIs to determine dynamics in program learning outcomes from general physics courses using simulated visual-dynamic computer modelling.

4. Results and discussion

Maxwell’s theoretical justification [48] of the general velocity distribution form was subsequently experimentally confirmed by Stern [49,50] and others.

We utilized these foundational ideas on ideal gas molecule velocity distribution and their subsequent scientific development to formulate a methodology for teaching molecular physics

definitions, characteristics, and processes through an integrative, generalizing approach to conceptual content essence, accompanied by computer simulation of ideal gas properties presented as visual and dynamic computer graphical models. This constitutes the essence of our integrative method of visual and dynamic computer modelling for studying distributions not only of ideal gas velocities but also of molecules, atoms, ions, electronic and phonon gases, with visual representation using Python's Matplotlib module. The study object was a defined volume V at constant temperature T , containing N molecules of substance with molar mass μ (figure 1).

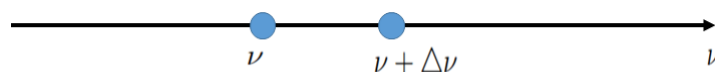


Figure 1. Speed neighborhood representation.

When developing program code, it is essential to define input data as physical parameters. Based on experimental research data and self-organization principles, using our developed computer program, we obtained molecular velocity distribution by velocity intervals and probable molecule numbers in interval ΔN . Following traditional research approaches, for computational convenience, we typically select a constant volume containing 10^6 molecules with constant initial parameters $T = 273\text{ K}$, $p = 1.013 \cdot 10^5\text{ Pa}$ [51].

According to the Maxwellian molecular velocity distribution model and molecular kinetic theory, gases occupy their containing vessel's volume. Following self-organizing system laws, molecules move continuously and chaotically in all equivalent directions, with velocity parameters dependent on temperature. It should be emphasized to students that for simplicity, rather than considering all arbitrary directions, absolute velocities of all molecules are generalized. Calculations readily show that through chaotic motion, each molecule experiences approximately 10^9 impacts per second [14, p. 354]. Consequently, it is improbable that all or most molecules would transfer their energy to one or several molecules [51, p. 29]. Similarly, molecules with zero velocity cannot exist. Thus, extremely low and high velocities compared to average velocity are improbable, with probability approaching zero for $\nu = 0$ and $\nu = \infty$. Therefore, standard practice involves dividing velocities according to criteria of equivalent (within limits) physical gas system content.

In scientific research and technical applications, self-organizing thermal molecular motion is characterized by three representative velocities: arithmetic mean, root mean square, and most probable. The challenge involves calculating molecule numbers possessing each strictly defined velocity type and determining their distribution rule. This problem formulation is incorrect due to the vast number of molecules and motion equations, and because molecular velocity is continuous, making exact specification of particular velocities impossible. Therefore, the distribution problem should be reformulated: determining how many molecules from the total population have velocities within specific intervals around given values.

This leads to the conclusion that molecular velocities are grouped (self-organized) around certain probabilistic values [14, p. 355]. If we imagine an instantaneous snapshot of all molecular velocities arranged linearly, they exhibit varying densities across different regions $\frac{\Delta N_\nu}{\Delta \nu} = \rho$ (figure 1).

Density decreases approaching zero or infinity. Differential calculus enables more detailed investigation [52]. For an equilibrium state model with unchanging parameters (temperature, pressure, molar mass, etc.), molecular velocity distribution remains constant, as does distribution density. For multiple separate volumes of identical gas under identical conditions, velocity distribution remains uniform. Researchers utilize this fact as the foundation for determining molecular distribution along specific directions or by absolute velocity values, which are

interrelated. Since molecular absolute velocity or coordinate axis projection has continuous values from zero to infinity (though this approximation is limited by finite light speed), a continuous velocity distribution function must exist. To establish this function, the gas is considered in equilibrium, implying time-independence. Within the x-axis velocity projection interval $\square \nu_x, \nu_x + \Delta \nu_x \square$, the probability is $d\omega(x) = f(\nu_x^2)d\nu_x$ (by probability definition $d\omega(x) = f(x)dx$ [51, p. 23]), where $f(\nu_x^2)$ represents the distribution function of independent random variables. The velocity squared indicates that the distribution function is independent of velocity projection direction probability, maintaining consistent shape and constant normalization factor for N particles. Similarly, $d\omega(\nu_y) = f(\nu_y^2)d\nu_y$ and $d\omega(\nu_z) = f(\nu_z^2)d\nu_z$, with $\nu = \sqrt{\nu_x^2 + \nu_y^2 + \nu_z^2}$ [15, p. 43–55].

Probability theory establishes that all independent projection components of random velocities on coordinate axes, simultaneously possessing values within specific intervals, are calculated through probability products $d\omega = d\omega_x d\omega_y d\omega_z$ [13, p. 43–55]. Accordingly, the probability of a molecule simultaneously possessing three velocity projections as independent random variables within corresponding intervals is determined by: $d\omega(\nu_x, \nu_y, \nu_z) = f(\nu_x^2)d\nu_x f(\nu_y^2)d\nu_y f(\nu_z^2)d\nu_z = f(\nu_x^2 + \nu_y^2 + \nu_z^2)d\nu_x d\nu_y d\nu_z$, where $dV = d\nu_x d\nu_y d\nu_z$ represents the velocity volume element.

Based on these results, we analyzed traditional definitions of chaotic motion (without preferred motion direction [14, p. 302]) and equilibrium state (invariability of system thermodynamic parameters [51, p. 307]). Following Maxwell [48], we propose defining the equilibrium state as a model wherein self-organizing processes ensure that molecule numbers with identical velocities before collision equal those after collision [32, p. 72]. This approximates an analogy with vibration system models [24]. We propose that this leads to a refined concept of chaotic motion: “self-organizing molecular motion is completely chaotic if molecular velocities obey Maxwell distribution” [32, p. 72]. This definition of chaotic motion is most complete and reasonable, rendering the model visual.

Based on fundamental definitions of ideal gas chaotic motion and state equilibrium, we clarified the physical meaning of velocity, temperature, momentum, absolute pressure, energy concepts and their properties [32]. These established parameters enable Python program creation for constructing simulated dynamic Maxwell distribution models for four gases: helium, nitrogen, oxygen, and carbon dioxide at 300 K temperature across velocity ranges from 0 to 1400 m/s with 10 m/s increments (figure 2). We account for self-organized molecular movement, whereby gas molecular movement speed is volume-independent. The distribution function was selected for 10^6 gas molecules [51, pp. 25, 28]. Based on these defined parameters, the following program code was created:

```
import matplotlib.pyplot as plt
import numpy as np

# input data initialisation
miu_co2 = 44
miu_o2 = 32
miu_n2 = 28
miu_he = 4
T = 300
R = 8.31*10**3

# calculating the value of constant A
A_co2 = 4*np.pi*(np.power(miu_co2/(2*np.pi*R*T), 3/2))
A_o2 = 4*np.pi*(np.power(miu_o2/(2*np.pi*R*T), 3/2))
```

```

A_n2 = 4*np.pi*(np.power(miu_n2/(2*np.pi*R*T),3/2))
A_he = 4*np.pi*(np.power(miu_he/(2*np.pi*R*T),3/2))

# determination of the x-axis values
v = np.arange(1,1400,10)

# distribution calculation
distr_co2 = [A_co2*v**2*np.exp(-(miu_co2*v**2)/(2*R*T))
for v in np.arange(1,1400,10)]
distr_o2 = [A_o2*v**2*np.exp(-(miu_o2*v**2)/(2*R*T))
for v in np.arange(1,1400,10)]
distr_n2 = [A_n2*v**2*np.exp(-(miu_n2*v**2)/(2*R*T))
for v in np.arange(1,1400,10)]
distr_he = [A_he*v**2*np.exp(-(miu_he*v**2)/(2*R*T))
for v in np.arange(1,1400,10)]

# graph construction
plt.plot(v, distr_co2, label = 'CO'+chr(8322)+' (44)')
plt.plot(v, distr_o2, label = 'O'+chr(8322)+' (32)')
plt.plot(v, distr_n2, label = 'N'+chr(8322)+' (28)')
plt.plot(v, distr_he, label = 'He (4)')

# x-axis labeling
plt.xlabel('v - velocity')

# y-axis labeling
plt.ylabel('f(v)')

# legend output
plt.legend()

# graph output
plt.show()

```

In general physics courses, various velocity types are distinguished. Their introduction has evolved historically: arithmetic mean velocity has long been utilized. With thermodynamics development, additional concepts became necessary: molecular velocity projections on coordinate axes ν_x, ν_y, ν_z ; average velocity squared value ν^2 ; squared average velocity value $\overline{\nu^2}$; root mean square velocity $\sqrt{\overline{\nu^2}}$.

When deriving the formula for gas pressure on vessel walls $\frac{F}{s} = p + nm\nu_x^2$, existing textbooks assume a model where all gas molecules possess identical velocity projections ν_x , which is inaccurate, as noted by Kikoin and Kikoin [14, p. 22]. Subsequently, without proper mathematical justification, ν^2 is replaced by its average value $\overline{\nu_x^2}$ for each individual molecule $\nu^2 = \nu_x^2 + \nu_y^2 + \nu_z^2$. The averaging operation then follows: $\overline{\nu^2} = \overline{\nu_x^2 + \nu_y^2 + \nu_z^2} = \overline{\nu_x^2} + \overline{\nu_y^2} + \overline{\nu_z^2}$. Subsequently, assuming chaotic molecular motion yields $\overline{\nu_x^2} = \overline{\nu_y^2} = \overline{\nu_z^2}$ and $\overline{\nu_x^2} = \frac{\overline{\nu^2}}{3}$. Consequently, $p = \frac{1}{3}nm\overline{\nu^2}$. This methodology for substantiating gas pressure on vessel walls is approximate with considerable error. Considering ideal gas chaotic motion, mean square velocity exceeds average molecular velocity by approximately 9

The computer program eliminates this limitation, enabling not only dynamic model construction of molecular velocity distribution but also tracing this distribution in any velocity

neighborhood through graphs, consequently generating distribution tables indicating velocity intervals with corresponding probable molecule numbers in interval ΔN (quantity) and relative molecular fraction $\frac{\Delta N}{N}$.

We now analyze computer modelling results. The area bounded by the distribution curve and abscissa axis represents the total molecule number in the vibration system, which in relative terms equals unity [51]. Selecting a fixed volume with 10^6 molecules allows extension to any volume as needed [15, p. 187]. From the total 10^6 particles, approximately 728,000 carbon dioxide molecules (72.8

Most molecules are distributed from 700 m/s (corresponding to 73,000 molecules) to 1750 m/s with molecule numbers (from 1000 to 1750) of approximately 314,000. The function graph's right portion (figure 2) extends more than the left, with values decreasing more intensively. As with other gas molecules, the basic number approximates 740,000, slightly higher for noble gases. Freik and Lysak [51, p. 25] demonstrated that for oxygen velocities at 290 K temperature below 100 m/s, approximately 1/7 of all molecules are accounted for; the 200-600 m/s interval contains 3/4 of molecules; the over-600 m/s interval contains 1/6.

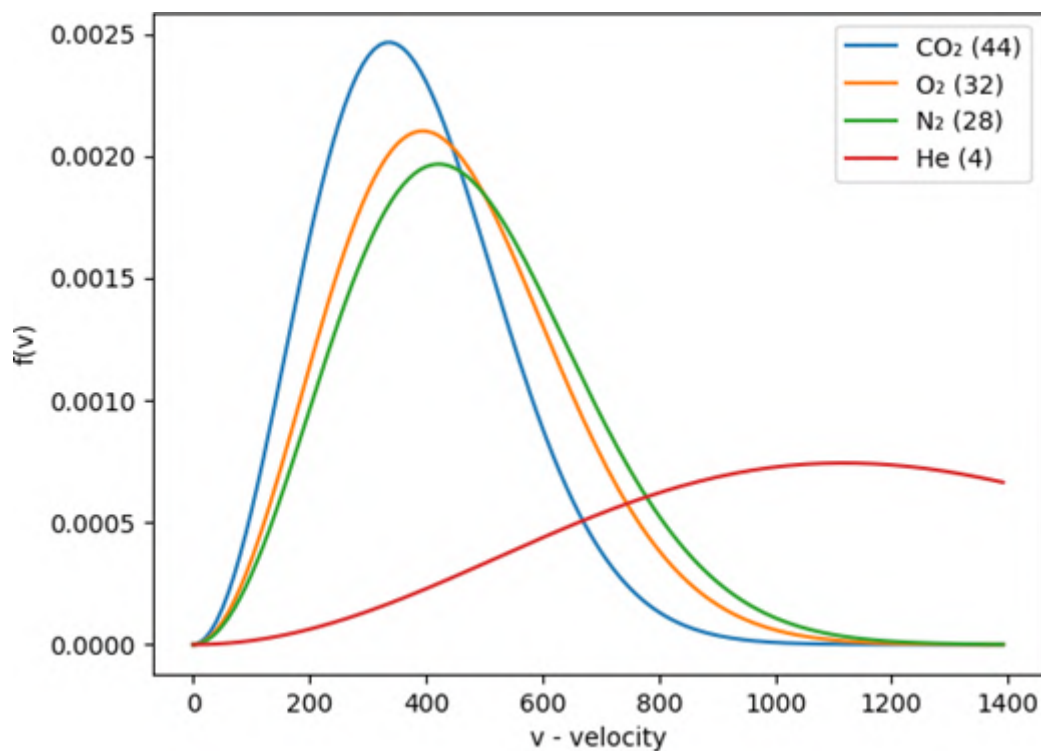


Figure 2. Velocity distribution of nitrogen, carbon dioxide, oxygen, and helium molecules.

The computer program also enables construction of simulation-dynamic graphs investigating distribution as a temperature function for nitrogen molecules (figure 3). Temperature changes, following self-organizing laws, lead to velocity redistribution (by magnitude) and corresponding maximum curve shifts along the abscissa axis rightward. Calculating the area between curve and abscissa axis for each studied case reveals it remains unchanged, while curve maximum decreases and becomes less pronounced, with the curve flattening. As temperature increases, distribution becomes more uniform, molecules with velocities exceeding ν_y increase, and low-velocity molecules decrease. This is confirmed by experiments on actual chemical reaction acceleration when mixtures are heated [34, pp. 25-26]. In plasma studies, after several particle collisions, velocity distribution becomes Maxwellian.

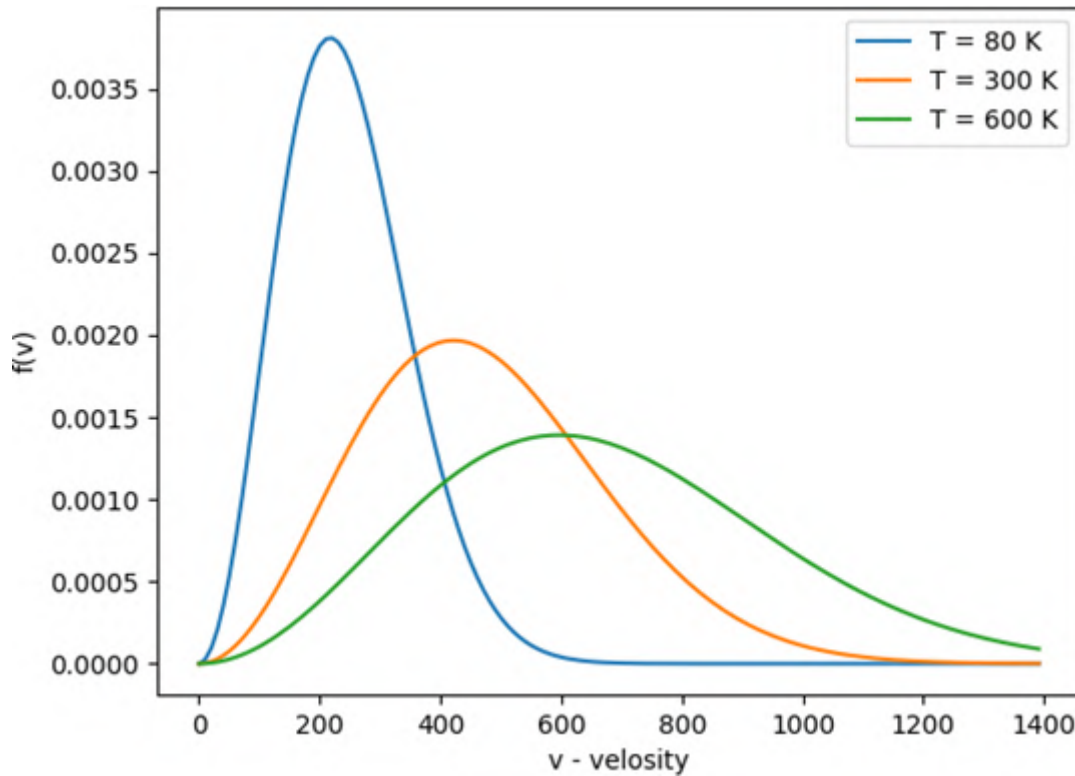


Figure 3. Nitrogen molecule distribution at various temperatures.

This approach establishes the physical meaning of parameter α in Maxwell's mathematical model $f(x) = \frac{1}{\alpha\sqrt{\pi}}e^{-\frac{x^2}{\alpha^2}}$ and its temperature relationship. Temperature being a thermodynamic parameter, we considered whether absolute pressure, impulse, energy, and other thermodynamic parameters can be expressed through Maxwellian distribution and their properties analyzed using computer programs.

We constructed momentum distribution graphs for helium, nitrogen, oxygen, and carbon dioxide molecules (figure 4). The horizontal axis displays momentum parameters; the vertical axis shows distribution function values. For clarity, the vertical axis scale for carbon dioxide and oxygen differs from that for nitrogen and helium.

Comparing the obtained graphs (figure 4), we conclude that with increasing molar mass, they become steeper, indicating non-uniform impulse decay. The dynamic graphs can be studied simultaneously on monitors or by adjusting gas parameters separately. We conclude that self-organizing gas impulse distribution by velocity on vessel walls is determined by molecules according to Maxwell distribution. The developed computer program enables creation of laboratory work systems, experimental tasks, creative projects, and demonstration experiments for studying ideal gas properties.

To determine gas pressure on obstacle walls, it is necessary to know molecule numbers in the neighborhood $\square \nu_z, \nu_z + \Delta\nu_z \square$. These molecules interact among themselves and with obstacles, transmitting impulses that determine absolute gas pressure. Assuming unit volume per unit time, molecule numbers in the given velocity projection neighborhood are determined by: $dn(\nu_z) = \nu_z dn_0(\nu_z) = \nu_z dn_0 \sqrt{\frac{\alpha}{\pi}} e^{-\alpha\nu_z^2} d\nu_z$ [32, p. 60]. The defined molecules cause absolute pressure at given temperature $d\rho(\nu_z) = 2m\nu_z dn(\nu_z)$, respectively $p = \int d\rho = \int 2m\nu_z dn(\nu_z)$.

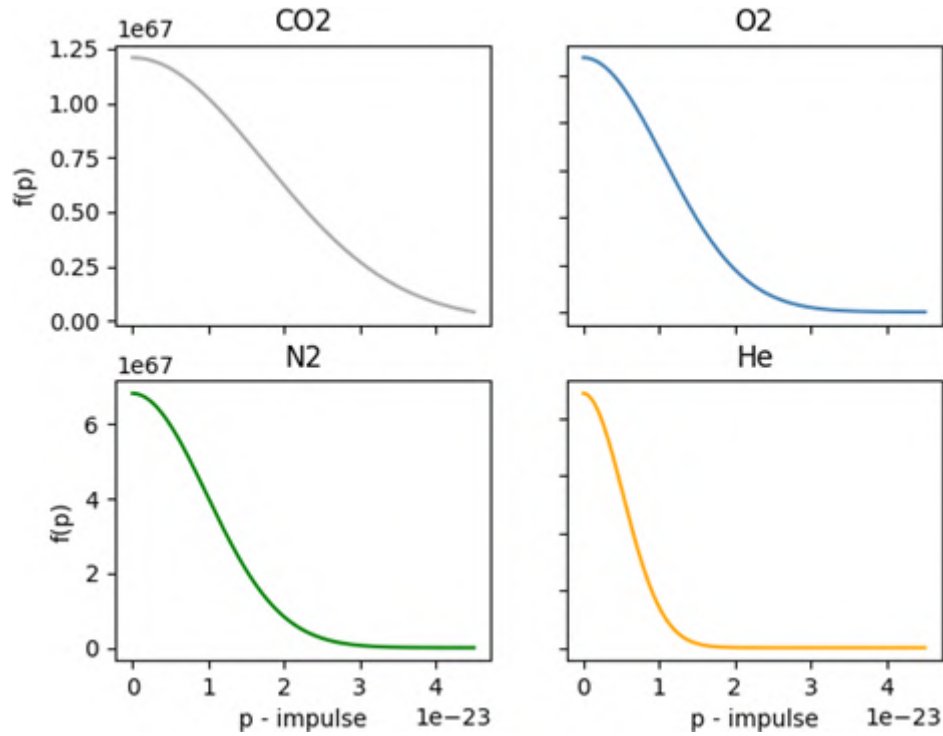


Figure 4. Maxwell distribution by molecular momentum.

For velocity interval $\square 0, \infty \square$, then $p = 2mn_0 \sqrt{\frac{\alpha}{\pi}} \int_0^\infty e^{-\alpha v_z^2} v_z^2 dv_z = \frac{mn_0}{2\alpha}$. Thus, we conclude that self-organizing gas absolute pressure on vessel walls is determined by molecules according to Maxwell distribution.

Considering molecular kinetic theory provisions and gas state equations yields $\frac{mn_0}{2\alpha} = kTn_0$, $\alpha = \frac{m}{2kT}$. Then the velocity distribution expression for specific gas creating absolute pressure on vessel walls becomes: $f(v) = \frac{\Delta N}{N} \Delta v = 4\pi \left(\frac{m}{2\pi kT}\right)^{\frac{3}{2}} v^2 e^{-\frac{mv^2}{2kT}}$. By increasing temperature in the program code, we observe curve shifts toward higher velocities. Generally, molecular velocity distribution remains unchanged, ensuring areas under curves at any temperature remain constant under normalization conditions. This yields the important conclusion that according to gas molecular self-organization movement laws, with temperature increase, higher-velocity molecule numbers increase at the expense of lower-velocity molecules. Such systems somewhat analogize mechanical vibration systems [24].

Beyond specific aspects, computer modelling of Maxwell distribution for analyzing translational molecular kinetic energy dependence on gas parameters thoroughly reveals Avogadro's law content: equal volumes at constant pressure and temperature ($p = const, T = const$) contain equal molecule numbers. Based on computer dynamic graphs of molecular velocity distribution in different gases (varying molar masses), the reason for equal molecule numbers under specific conditions is identified. This represents an important conclusion, as real gases exhibit minor deviations from ideal gas patterns. Additionally, Maxwell distribution explains the physical meaning of gas state equations $F(p, V, T)$, which in molecular kinetic theory takes the form $p = nkT, n = \frac{N}{V}$, consequently yielding all gas laws studied in general physics courses.

Computer dynamic simulation modelling of Maxwell distribution more thoroughly explains thermodynamics laws from molecular kinetic theory perspectives: the first law (energy

conservation), where molecular velocities are embedded in internal energy and work performed; the second law of thermodynamics, based on analyzing computer dynamic Maxwell distribution graphs for two temperatures, clearly defines thermodynamic process directions and explains Clausius' theorem: $\oint \frac{\delta q}{T} = 0$, $\frac{\delta q}{T} = dS$, where δq represents reduced heat and S represents entropy.

Through simulated computer graphs of molecular velocity distribution, the physical meaning of heat capacity concepts in thermodynamics is more comprehensively revealed, where vibrational and potential internal energy components are not considered.

The defined approach of applying graphical computer analysis to molecular velocity distribution enables explanation of atmospheric research results. Specifically, it becomes possible to determine the proportion of molecules acquiring Earth's second cosmic velocity of $1.12 \cdot 10^4$ m/s, escaping Earth's atmosphere and dispersing into space. Computer process modelling enables outlining prospects for such scattering.

The effectiveness of the considered integrative method for forming fundamental molecular physics, thermodynamics, and electrodynamics concept content based on simulation visual and dynamic computer modelling of molecule, atom, electron, and phonon gas ion velocity distribution using Python's Matplotlib module was selectively tested through pedagogical experiments at Volodymyr Vynnychenko Central Ukrainian State University and Dnipro State Medical University. The pedagogical experiment involved teachers and 56 experimental group students and 42 control group students (figure 5).

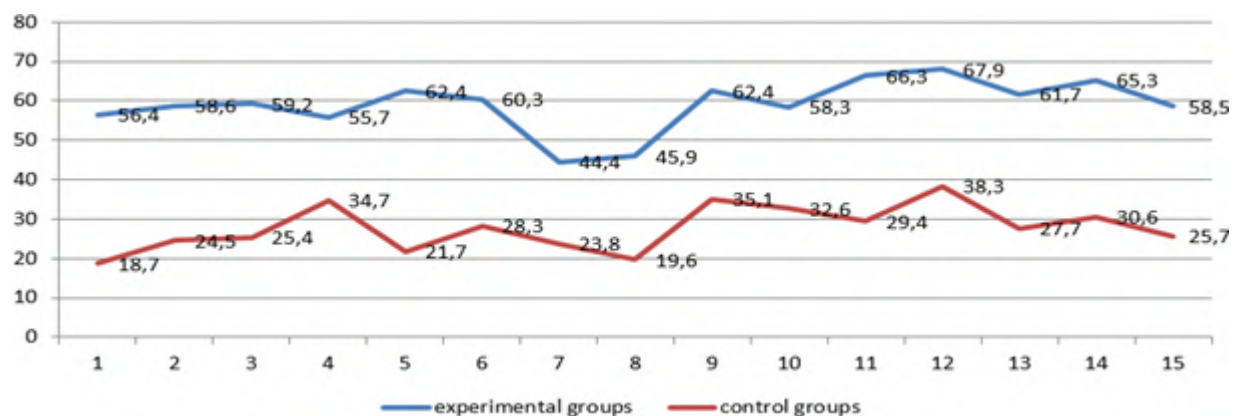


Figure 5. Student knowledge monitoring results.

Assessment of subject competence formation level on the selected topic was determined by the mastery coefficient $k = \frac{N_{cor}}{N_{tot}}$, where N_{cor} represents correct answers and N_{tot} represents total answers across 15 indicators: knowledge of “simulation visual and dynamic computer modelling” concept (1); programming language proficiency (2); ability to create computer programs for distribution analysis (3); understanding of physical world picture concepts (4); knowledge of Maxwell distribution physical essence (5); knowledge of graphical simulation modelling concepts for molecule, atom, ion, electron, and phonon gas distribution (6); ability to analyze computer graphs (7); ability to apply probability theory knowledge for microscopic state analysis (8); equilibrium state definition (9); chaotic motion definition (10); temperature definition (11); absolute pressure definition (12); “digitalization” concept essence (13); outlining velocity distribution role in ideal gas model property analysis (14); knowledge of space dimensionality (15).

The graph (figure 5) demonstrates that the considered integrative method for forming fundamental molecular physics and thermodynamics concept content based on dynamic

computer modelling simulation of molecular velocity distribution using Python's Matplotlib module in natural science teaching has proven effective. Experimental groups showed positive trends in increasing subject competence levels on the research topic compared to control groups (figure 5).

5. Conclusions

Theoretical and practical investigation of information sources reveals that smart educational environments are currently transitioning from educational models of information accumulation to information models emphasizing development and result quality improvement. Accordingly, conditions are being established for integrating computational resources with cyber-physical natural phenomena essence through transitioning from traditional mathematical gas phenomena modelling to simulation computer modelling of atomic and molecular gas states. Such computer modelling is facilitated by Python and its NumPy and Matplotlib modules. This led us to develop an integrative method of visual dynamic computer modelling for gas molecule velocity distribution using Python's Matplotlib module. The resulting visualization, termed integrative presentation-dynamic computer visualization, provides graphical representation through programming tools that, combined with velocity distribution explanations, generates novel definitions for particle impulses on vessel walls, gas pressure determination, and kinetic energy determination. The roles of arithmetic mean, root mean square, and most probable velocities in these processes are revealed. From the proposed method's perspective, the physical meanings of velocity, temperature, momentum, absolute pressure, energy concepts and their properties are clarified. The established parameters enable Python program creation for building graphical simulation models of Maxwell dynamic distribution. This approach develops students' computational thinking, fosters worldviews oriented toward independent truth-seeking, and provides opportunities to implement research ideas directly during studies, as confirmed through pedagogical experimentation.

The study results indicate a need for practical revision of content formation approaches in molecular physics and electrodynamics (electronic phenomena in various media), which have remained at late nineteenth and early twentieth century levels.

Future research should expand programming capability utilization to enhance the proposed method and establish, on its foundation, integrative simulation presentation and dynamic visualization for teaching gas and electronic phenomena and processes with variable parameters.

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Experience in the development and implementation of the course “Python for Physics Teachers”

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Abstract. The study explores the integration of programming into the professional development of prospective physics educators. The study emphasizes the development of practical skills in computational methods and data visualization. The course is structured into 13 lectures and 12 practical sessions. The lectures cover foundational Python programming, visualization of physical phenomena, and modeling of school physics topics. The practical sessions focus on the application of these skills. The study underscores the contemporary relevance of integrating Python, a widely adopted programming language in science and education, into the pedagogical training of physics teachers. The course aligns with STEM education principles, enabling participants to model, analyze, and visualize physical phenomena, thus bridging theoretical physics concepts and real-world applications. This integration equips future educators with critical digital competencies to meet the demands of modern educational practices. The study uses an adapted Course Experience Questionnaire (CEQ) to assess student satisfaction and the effectiveness of the course. The findings indicate a high level of satisfaction in various domains, including teaching quality, clarity of objectives, and practical relevance. However, the study also identified challenges, such as the need for additional support for students without previous programming experience. This research contributes to the broader discourse on educational innovation by demonstrating the feasibility and benefits of incorporating computational tools like Python into physics education. The study offers actionable information for curriculum development and underscores the potential to cultivate computational literacy among prospective educators.

1. Introduction

The pertinence of the present study lies in its examination of the utilization of the Python programming language in physics experiments and educational projects, a matter of particular relevance in the contemporary educational landscape. Current trends in education require the integration of digital technologies and computational methods into the educational process [1,2]. Python, an open-source high-level programming language, has seen a surge in popularity in research and education due to its inherent simplicity, flexibility, and abundance of libraries available for scientific computing and data visualization [3–5].



In the field of physics education, the practice of physical experimentation is widely recognized as an integral component of the curriculum. This approach enables students to engage directly with observable physical phenomena, facilitating the development of a deeper understanding of the underlying theoretical concepts. The incorporation of Python into this setting presents novel opportunities for the design and execution of experiments, a matter of particular significance in scenarios where access to laboratory equipment is constrained. The use of Python facilitates the establishment of virtual laboratories, allowing students to conduct experiments, modify parameters, and observe the resulting phenomena in real time. This approach has been shown to improve interest in the subject matter while also cultivating critical thinking and analysis skills.

Visualization of physical processes plays a pivotal role in the educational process as it facilitates students' comprehension of abstract concepts through graphical representation of data. Python libraries, such as Matplotlib and SeaBorn, offer sophisticated tools for the creation of graphs, diagrams, and three-dimensional models that illustrate a range of physical phenomena. This improves the intuitiveness of complex concepts and improves learning outcomes.

In the contemporary world, STEM education (science, technology, engineering, and mathematics) has gained increasing importance in preparing students to solve complex problems and foster innovative thinking [6–8]. Integrating a Python course into physics education aligns with STEM principles, as it combines scientific knowledge with technological skills and computational methods. This provides students with the opportunity to apply their knowledge in practice while developing programming and engineering skills.

In the contemporary scientific landscape, computational methods have become an integral component of modern research and scholarship. Integration into the educational process is imperative to cultivate competitive specialists in various fields. Incorporation into physics education facilitates the introduction of students to the foundational principles of numerical modeling, data analysis, and algorithmic thinking. This approach not only enhances students' existing knowledge, but also prepares them for future academic pursuits and professional endeavors within science and technology related disciplines.

The efficacy of integrating Python into physics education has been validated by scientific research. A study by Tufino et al. [9] demonstrates that the incorporation of Python into physics laboratory courses enhances students' computational skills and professional practice. Additionally, Mintii's [10] study underscores that the utilization of the Python project method in the training of future physics and computer science teachers contributes to the cultivation of essential competencies.

Consequently, there is an urgent and pressing need to prepare physics teachers to utilize Python in physics experiments and educational projects. This is essential to ensure the quality of education that meets contemporary requirements and trends in the development of science and technology.

The objective of this study is twofold: first, to develop and substantiate methodological approaches to the training of physics teachers that are aimed at the effective use of the Python programming language in physics experiments and educational projects; and second, to assess the degree of satisfaction of future physics teachers with the educational course after studying it.

The purpose of the study is to investigate the process of developing, implementing, and evaluating the effectiveness of the "Python for Physics Teachers" aimed at developing basic programming skills, modeling physical phenomena, and using digital technologies in the educational process.

2. Theoretical background and context

The integration of programming and physics, particularly through the use of languages such as Python, has garnered significant attention within academic institutions. This approach improves students' understanding of complex physical phenomena and equips them with the requisite computational skills.

In academic institutions, the incorporation of Python into computational physics courses has been investigated as a means of enhancing numerical modeling and data analysis capabilities. Backer [11] has explored the integration of Python into the realm of computational physics education, underscoring its accessibility, and emphasizing the efficacy of graphical visualizations in enhancing student comprehension.

The integration of programming into introductory physics courses at the high school level has been a subject of consideration. A pilot program, as outlined by VanKerhove [12], underscores the significance of computational skills in contemporary science and provides strategies for the incorporation of programming into high-school physics curricula.

The utilization of programming in the pedagogy of experimental physics has been further investigated through the development of virtual physics experiments. Lang et al. [13] delineate the design and implementation of virtual-physics experiments using Unity and visual programming, thereby providing an innovative approach to physics education that employs programming to model physical phenomena.

The impact of programming on enhancing students' comprehension of physical concepts has been investigated through the use of robots. Ferrarelli and Iocchi [14] present an instructional method in which students perform Newtonian physics experiments by programming a mobile robot, enabling them to design, implement, and visualize physical concepts, thereby employing the robot as a cognitive instrument.

The integration of programming into physics education has also been considered through the lens of computational thinking, as discussed by Dwyer et al. [15]. These researchers explore how involving students in developing and using models of physical phenomena through programming can improve their computational thinking skills, which are important for solving problems in physics.

The integration of programming in physics education has also been explored through the development of educational resources. Faes [16] presents a series of Python experiments in physics and astronomy, providing detailed solutions to topics that are not usually covered in depth, thereby offering valuable resources for teachers and students.

The integration of programming in physics education has been further supported by the development of open-source tools. The Open Source Physics Project, for instance, provides libraries and tools for physical modeling, thereby promoting the inclusion of programming in physics education and allowing students to engage in computational modeling [17].

Numerous scientific studies have emphasized the efficacy of the Python programming language in enhancing students' comprehension of complex physical phenomena, particularly in the context of visualizing physical processes, constructing graphs, and creating diagrams in school education.

In their study, "Digital technologies in teaching physics: an analysis of existing practices", Yurchenko et al. [18] examined the perceptions of physics teachers and students regarding the utilization of digital technologies, particularly Python, in the educational environment. They highlighted the potential of these technologies to improve the learning process.

Savenko et al. [19] present a comprehensive study on modeling physical processes using Python, supplemented by graphical user interfaces (GUIs). By integrating iterative algorithms and molecular dynamics methods, they demonstrate the usefulness of Python in modeling complex physical phenomena, such as phase transitions in two-dimensional systems. The study emphasizes the importance of interactive visualization in physics education, suggesting that

Python's capabilities can greatly aid in understanding complex physical processes.

The integration of Python programming into physics instruction in STEM curricula has been a subject of extensive research in the academic literature, emphasizing its effectiveness in improving computational skills and deepening students' understanding of physical concepts. A notable study by Charles and Gwilliam [20] examines the challenges faced by undergraduate physics students learning Python, particularly the cryptic nature of error messages that can hinder learning. The researchers developed a tool that translates Python error messages into plain English, allowing students to resolve coding errors independently. The findings suggest that this approach mitigates students' anxiety and fosters confidence in their programming abilities, thus enhancing the efficacy of the learning process.

Borovský et al. [21] present SageMath, an open-source Python-based environment for scientific computing, in the context of physics education. Their work illustrates how SageMath serves as a versatile tool for symbolic, numerical, and visualization problems, improving students' problem-solving skills. The authors advocate for the implementation of such open digital environments in STEM education to promote interactive learning and engagement with complex interdisciplinary problems.

The work by Tufino et al. [9] explores the integration of Python data analysis into a first-year physics laboratory course. They developed exercises using Jupyter Notebooks that help students process and analyze data in Python while performing experimental tasks. The study shows that early incorporation of computational skills into laboratory courses increases students' proficiency in data analysis and promotes professional practice aligned with current scientific research.

Briceño and Rogers [22] delineate the Python4Physics curriculum, which aims to cultivate interest in physics among high school and early college students through small Python-based projects. Their experience demonstrates that such initiatives can effectively bridge the gap between theoretical physics concepts and practical computational applications, thereby enriching the educational experience and inspiring future pursuits in the physical sciences.

In a similar vein, Landau et al. [23] present a cogent argument for the incorporation of Python into the realm of computational physics education, asserting its potential to surpass the efficacy and efficiency of conventional pedagogical approaches. The study underscores Python's pivotal role in the presentation of intricate physical models and simulations, a role that is poised to enhance students' analytical and problem-solving competencies.

Wang and Wang [24] work presents a comprehensive approach to computing in the physical sciences, emphasizing interactive computing, data analysis, and visualization with Python. Their work serves as a primary resource for integrating computational methods into physics education, promoting a deeper understanding of physical systems through computational modeling.

The present study will address the issue of training physics teachers to utilize the Python programming language in a school physics course. A review of recent research indicates a growing emphasis on the integration of digital technologies into the educational process. In particular, the study by Yurchenko et al. [18] underscores the significance of introducing digital technologies in physics teaching, with 80% of the surveyed teachers asserting its necessity to enhance teaching effectiveness.

Pavshuk and Harieieva's [25] study explores the application of the Python programming language in physics education, emphasizing its capabilities in modeling physical processes, solving differential equations, and analyzing signals. The authors underscore the potential of Python to enhance students' comprehension of physical concepts and laws.

The article by Sadovyi et al. [26] provides a comprehensive discussion on the integration of scientific graphics in the pedagogy of physics and technical disciplines at universities dedicated to education. The authors underscore the necessity to discern between scientific and presentation visuals, emphasizing that scientific graphics play a pivotal role in fostering students' research and digital competencies. The utilization of the Python programming language, particularly its

NumPy and Matplotlib modules, facilitates the creation of scientific graphs, thereby enhancing the quality of learning and inspiring students to pursue studies in physics.

Mintii's [10] research focuses on the methodology of cultivating programming competencies in prospective physics and computer science educators through the project method, with the Python language selected as the primary implementation tool for projects involving the modeling of physical processes, such as the movement of a body under the influence of a force or the modeling of the solar system. Utilizing the project method has been shown to contribute to the development of not only specialized professional competencies but also key competencies, including educational, mathematical and natural science competencies.

Linnik et al. [27] concentrate on the implementation of computer modeling technology in the course "Object-Oriented Programming" for students of physics and mathematics faculties of pedagogical universities. The authors justified the choice of Python and its VPython library for modeling physical processes, emphasizing that this approach allows students to focus on the essence of the modeled phenomenon without being distracted by the details of the user interface implementation. The proposed methodology contributes to the development of students' skills in object-oriented programming and computer modeling, which are necessary for the effective use of Python at school.

The integration of the Python programming language into the training of future physics teachers signifies a pivotal step in enhancing their professional competence and adaptability to contemporary educational standards.

The selection of appropriate Python libraries is paramount to ensure effective learning. Specifically, the NumPy library furnishes potent instruments for the manipulation of multidimensional arrays and the execution of mathematical operations, which form the foundation for the processing of physical data. SciPy extends the functionalities of NumPy by providing supplementary operations for scientific and engineering calculations, including the solution of differential equations and optimization. Matplotlib offers data visualization tools that enable users to generate graphs and charts to illustrate physical phenomena. The utilization of these libraries is instrumental in fostering students' competencies in modeling and analyzing physical processes [25].

The development of educational materials should take into account the gradual complexity of tasks, beginning with fundamental programming concepts and progressing to more intricate projects that model real physical phenomena. The utilization of the project method, as demonstrated in Mintii's [10] study, fosters the development of programming competencies in prospective physics and computer science educators. Engaging students in the development of their own software products to model physical processes enhances their motivation and comprehension of the subject matter.

The organization of practical classes should prioritize interactive learning, using tools such as Jupyter Notebooks or Google Colab that facilitate direct interaction with code, experimentation with parameters, and immediate visual feedback. This approach fosters a deeper understanding of physical phenomena and cultivates computational thinking skills. A study by Tufino et al. [9] underscores the efficacy of Jupyter Notebooks in physics education, underscoring their role in honing students' computational aptitudes.

The integration of Python into the realm of physics teacher education necessitates a systematic approach that encompasses the selection of suitable tools, the development of adapted teaching materials, and the organization of practical classes that prioritize student engagement in the learning process.

3. Research methodology

The development of the course, "Python for Physics Teachers", was meticulously planned, taking into account contemporary trends in physics education and programming, as well as

an exhaustive analysis of the requirements of prospective physics educators. Contemporary methodological guidelines underscore the imperative to incorporate STEM education, a multifaceted approach encompassing science, technology, engineering, and mathematics, to cultivate critical thinking and hands-on capabilities of students. The incorporation of Python into the educational process is instrumental in achieving these objectives, as this programming language serves as an effective medium for modeling and visualizing physical phenomena [28].

3.1. Structure and content of the course “Python for Physics Teachers”

The course, which is titled “Python for Physics Teachers”, has been developed for prospective education professionals. The course has been assigned a volume of 5 ECTS credits. In addition, it comprises 13 lectures and 12 practical classes. The key goal of the course is to develop students’ practical skills in using the Python programming language to model, analyze, and visualize physical phenomena and processes studied in the school physics course, as well as to integrate these tools into future teaching activities.

The course is divided into three logical modules:

- (i) *Python programming fundamentals.* This module (5 lectures, four practicals) lays the foundation by introducing students to Python syntax, data types, operators, conditional statements, loops, and functions. The practical part focuses on applying these fundamentals to solve simple physical problems (e.g., calculating velocity and energy) and basic data processing.
- (ii) *Visualization of physical processes.* In this module (4 lectures, four practicals), students master key visualization libraries – Matplotlib for building static graphs (dependencies of physical quantities, histograms) and VPython for creating dynamic 2D and 3D models of physical phenomena (motion of bodies, oscillations, trajectories). Emphasis is placed on visualizing physical concepts and experimental results.
- (iii) *Modeling of physical phenomena using Python.* The final module (4 lectures, four practicals) is devoted directly to computer modeling. Students learn to create numerical models of mechanical systems (motion under the influence of forces, pendulum) and basic electromagnetic processes (simple electric circuits). Particular attention is paid to the methodological aspects of integrating modeling into the school educational process, culminating in developing their educational project using Python.

An overview of the course structure and key aspects is presented in table 1.

3.2. Examples of practical tasks and their connection to physics

In order to facilitate a more profound comprehension of the practical implementation of the course and its emphasis on addressing the needs of physics educators, the following section presents a series of illustrative examples. These examples encompass the range of tasks students have performed, underscoring the pertinent physics concepts and the Python tools utilized.

An example of an assignment for the first module: “Data processing of the laboratory work “Study of equally accelerated motion””. Students received a CSV file with experimental data (time, coordinate). They had to write a Python script that reads this data and calculates the instantaneous velocity at different times (if there is enough data) and the average acceleration.

- Connection with physics: kinematics, equally accelerated motion, processing the results of a physical experiment.
- Python tools: basic file operations, NumPy lists/arrays, basic mathematical operations.

An example of a task for the second module: “Visualization of the motion of a body thrown at an angle to the horizon”. Students had to create a program that, given the initial speed and

Table 1. Structure and key components of the course “Python for Physics Teachers”.

Module title	Lectures / Laboratory work	Key topics and skills	Main libraries / Tools
1 Python programming fundamentals	5 / 4	Python syntax, data types, control structures (loops, conditions), functions, working with files. Skills: basic programming	Python (standard library)
2 Visualization of physical processes	4 / 4	Building 2D graphs, creating 3D dynamic visualizations. Skills: visualization of data and processes (motion, oscillations)	Matplotlib, VPython
3 Modeling of physical phenomena using Python	4 / 4	Numerical modeling of mechanical and simple electromagnetic systems, methodological aspects of integration into education. Skills: computer modeling, development of educational projects	Python (NumPy/SciPy indirectly), Matplotlib, VPython

angle of the throw, builds the trajectory of the body using Matplotlib. Optional: visualize the trajectories for different angles on one graph.

- Connections to physics: dynamics, gravity, ballistic motion.
- Python tools: Matplotlib, Python functions for calculating coordinates.

Example of the task for the third module: “Modeling a simple electric circuit”. Students had to write a program to simulate a transient process (for example, capacitor charging) in a simple RC circuit. They had to plot the voltage across the capacitor and the current against time using Matplotlib.

- Connection to physics: electricity, direct current, electrical circuits, transients.
- Python tools: NumPy (for numerical methods), Matplotlib, basic functions.

The examples provided demonstrate how the course successfully integrated the acquisition of foundational programming skills with their immediate application to modeling and analyzing physical phenomena pertinent to the secondary physics curriculum, thus reinforcing the highly applied nature of the learning experience.

3.3. Methodology for evaluating course effectiveness

A thorough analysis of the requirements for prospective physics educators has revealed that a firm grasp of digital technologies and the ability to seamlessly integrate them into pedagogical practices are essential competencies for effective instruction within contemporary educational institutions. This research underscores the importance of cultivating the methodological competence of physics and computer science instructors, grounding their pedagogy in the foundational tenets of the Concept of the New Ukrainian School [29].

When harmonizing the content of the course “Python for Physics Teachers” with the defined theoretical bases, we took into account the modern methodological recommendations for teaching physics, which emphasize the need to introduce active forms of learning and develop students’ ability to work with information, analyze, interpret, and evaluate data.

The course begins by familiarizing students with the basic concepts of Python programming, which meets the need to develop the information and communication skills of teachers. Mastering the basics of syntax, conditional statements, and loops lays the foundation for further application of this knowledge to solving physical problems.

The following modules are dedicated to the visualization of physical processes and the modeling of phenomena studied in the school physics course. The use of Matplotlib and VPython libraries allows students to create visual graphical representations, which promotes a deeper understanding of physical concepts and increases learning efficiency. This approach is in line with the recommendations for the implementation of STEM education, which emphasize the integration of science, technology, engineering, and mathematics into the educational process.

The course places particular emphasis on the use of Python for modeling physical phenomena, a practice that aligns with contemporary trends in physical education that underscore the significance of cultivating computational skills and the capacity to apply them in real-world settings. The course's curriculum encompasses the development of programs for simulating mechanical systems, electrical circuits, and other physical processes. These skills will equip future educators with the ability to seamlessly integrate these methodologies into their own teaching practice.

The course, titled "Python for Physics Teachers", meticulously integrates theoretical underpinnings with practical competencies essential for contemporary educators, equipping them with the tools to implement innovative teaching methodologies that align with current educational standards and guidelines.

The course was introduced as an elective course for students majoring in Secondary Education (Physics and Astronomy) at Berdyansk State Pedagogical University (BSPU). According to the educational and professional program, students have the opportunity to choose elective courses in the second year, allowing them to form an individual educational trajectory in accordance with their own cognitive interests and creative abilities.

The elective course, "Python for Physics Teachers", was developed with two key concepts in mind: current trends in teaching physics and programming and the improvement of information and communication competence of future teachers. The course is structured into 13 lectures and 12 practical classes with the primary objective of mastering fundamental programming skills in Python. Place special emphasis on modeling, solving, and visualizing physics course tasks.

The course was implemented using modern teaching methods, including interactive lectures, practical classes using computer technology, and project activities. Students were able to apply their knowledge in practice by developing programs for modeling physical phenomena, which contributed to a deeper understanding of theoretical material and the development of professional competencies.

The successful implementation of the course "Python for Physics Teachers" in other educational institutions necessitates the consideration of methodological aspects that ensure adaptation to a specific context. These recommendations are derived from the findings of the study and the analysis of contemporary educational approaches.

A fundamental step in this process involves a thorough analysis of the needs and existing educational programs to determine the feasibility of integrating the course. A critical factor in this assessment is the identification of the students' existing programming skills and their level of readiness to engage with Python. In instances where students lack prior programming experience, it is imperative to allocate additional resources to the introductory modules of the course, with the objective of imparting foundational Python skills. This can be achieved by increasing the number of practical classes or by supplementing the curriculum with additional training materials.

A critical component of this endeavor is the selection of appropriate software and learning environments. Python boasts a plethora of libraries that facilitate the visualization of physical

processes, including Matplotlib, VPython, NumPy, and SciPy. These libraries enable users to generate both rudimentary graphs and intricate dynamic models. The selection of a development environment, such as Jupyter Notebook, Google Colab, or Visual Studio Code, provides students with a user-friendly and intuitive interface to interact with code.

Integrating a project-based approach into practical classes is also recommended, as it has been shown to improve student motivation and participation in the learning process. Tasks that simulate real-world physical experiments or situations allow students to see the practical value of the knowledge they have acquired. For example, developing simulations of harmonic oscillations or electrical circuits not only allows students to develop programming skills but also to understand the physical essence of these phenomena.

It is imperative to pay particular attention to the evaluation methods employed. These methods should be designed to assess not only theoretical knowledge, but also practical programming and modeling skills. To this end, the utilization of tests, projects, or practical work that evaluate students' proficiency in applying Python to solve real-world physical problems is recommended.

Methodological support is imperative for educators who implement the course. This may involve conducting training sessions, developing instructional materials, or providing access to open resources on Python. The exchange of experiences among educational institutions also contributes to enhancing the quality of course implementation, thereby establishing a foundation for the effective utilization of the course in other educational institutions and fostering the development of digital competence among prospective physics educators.

The effectiveness of the course "Python for Physics Teachers" was evaluated by adapting the standard Course Experience Questionnaire (CEQ) [30] to the course's particularities. The modified questionnaire comprises five content blocks: quality of teaching, clarity of goals and standards, practical orientation, appropriate assessment, and overall satisfaction. The process of adapting and modifying the CEQ questionnaire for our course involved several stages.

The initial phase of the study involved a thorough examination of the original CEQ structure. The CEQ questionnaire comprises five distinct scales that evaluate various dimensions of the student experience, encompassing aspects such as quality of teaching, clarity of goals and standards, practical orientation, appropriate assessment and overall satisfaction. This structured framework served as the basis for the subsequent modification of the questionnaire. In the subsequent stage of the study, statements for each scale were meticulously developed based on the fundamental principles of the CEQ questionnaire, with careful consideration given to the specific context of the course, "Python for Physics Teachers".

The evaluation of statements in the standard CEQ questionnaire uses a five-point Likert scale, and this scale was used in our study. Each statement is evaluated on a five-point Likert scale, where 1 means "strongly disagree" and 5 means "strongly agree". This approach enables us to quantify the level of agreement with each statement and conduct further statistical analysis.

It should be noted that the CEQ questionnaire is not limited to closed-ended questions; some include open-ended inquiries, thus facilitating the articulation of students' perspectives on the most valuable aspects of the course and offering suggestions for enhancement. This approach enables a deeper understanding of the student experience and facilitates the identification of potential areas for course improvement.

Instructions for students were developed for the survey, with clear instructions provided at the beginning of the questionnaire. These instructions explained the purpose of the survey, emphasized its anonymity, and stressed the importance of honest responses to improve the course. The students were asked to read each statement carefully and select the level of agreement that best reflected their experience.

Following the development stage, a pilot study was conducted with a small group of students and faculty members. This preliminary trial aimed to assess the clarity of the statements and

the appropriateness of the scale for the course. The results of this study confirmed the relevance and reliability of the modified questionnaire in evaluating students' experiences in the course "Python for Physics Teachers".

Consequently, the modified CEQ questionnaire was adapted to the course's particularities, enabling the acquisition of detailed and pertinent information regarding student experiences and teaching effectiveness. This contributes to the continuous improvement of the educational process.

4. Results

The present study involved 19 students majoring in Secondary Education (Physics) at Berdiansk State University, who studied the course "Python for Physics Teachers" during the academic years 2022-2023 and 2023-2024. The CEQ questionnaire contained 16 statements grouped into five content scales, which were evaluated on a five-point Likert scale.

The objective was to assess the reliability of the questionnaire, for which Cronbach's α coefficient was used to evaluate the internal consistency.

The "Quality of teaching" scale exhibited a high degree of reliability, evidenced by an α coefficient of 0.84, indicating substantial internal consistency among questions regarding teaching methods and interaction with the instructor.

The scale titled "Clarity of goals and standards" exhibited an acceptable level of reliability, with a coefficient of $\alpha = 0.78$, suggesting that the questions within this scale are adequately coordinated and reliably measure the comprehension of the course objectives by students.

The scale evaluating the practical orientation of the course demonstrated an α coefficient of 0.80, suggesting a high degree of reliability in measuring the practical component of the course and its relevance to the needs of future physics teachers.

The assessment scale demonstrated an acceptable level of reliability with a coefficient of $\alpha = 0.73$, indicating sufficient consistency of the questions about the methods and criteria to evaluate the course.

The overall satisfaction scale exhibited an α coefficient of 0.76, which signifies sufficient reliability to gauge students' comprehensive perceptions of the course.

The analysis indicates the high reliability of the questionnaire developed, with all scales exhibiting acceptable internal consistency ($\alpha > 0.7$), thus validating their application for the quality assessment of the course. Notably, the scales "Quality of teaching" and "Practical orientation" exhibited particularly high reliability indicators, a crucial consideration given the course's objective of cultivating practical competencies in Python-based physical experimentation.

Consequently, the questionnaire can be regarded as a reliable instrument for the subsequent evaluation of the effectiveness of the course "Python for Physics Teachers" and its enhancement. However, it is recommended to periodically reevaluate reliability to confirm the stability of its psychometric characteristics when used with diverse student populations.

The subsequent phase involved the processing of the results derived from the students' responses through the implementation of descriptive statistics and analysis [31].

Descriptive details of the individual questions are presented in table 2.

Table 2. Descriptive statistics by individual questionnaire questions.

Questions	Mean	Median	Standard deviation	Min	Max	Q1	Q3
The instructor(s) provided lucid explanations regarding the utilization of Python for a physical experiment.	4.15	4.00	0.87	2	5	4.00	5.00
During the course of the classes, I was considered an active participant and was encouraged to pose questions and present my own concepts.	3.74	4.00	1.10	1	5	3.00	4.75
I received timely explanations and advice on challenging issues in the context of writing code.	4.42	4.00	0.68	3	5	4.00	5.00
In general, the instructor(s) contributed to my deeper understanding of the combination of programming and physical phenomena.	4.16	4.00	0.50	3	5	4.00	4.00
The objectives of the course, which included mastery of Python and physics, were clearly defined.	4.63	5.00	0.48	4	5	4.00	5.00
The course program and training materials were found to be consistent with the stated goals and objectives of the course.	4.32	4.00	0.67	3	5	4.00	5.00
The grading criteria for laboratory and project work were clearly defined and aligned with the course objectives.	4.26	4.00	0.73	3	5	4.00	5.00
The examples and projects completed during the course facilitated my understanding of the practical application of Python in a physical experiment.	4.68	5.00	0.59	3	5	4.00	5.00
It is evident that the programming skills that I have acquired can be applied in my future work as a physics teacher.	4.21	4.00	0.54	3	5	4.00	4.75

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Questions	Mean	Median	Standard deviation	Min	Max	Q1	Q3
Laboratory work was more closely aligned with the actual conditions of physical research, thereby facilitating the development of practical skills.	3.79	4.00	0.54	3	5	3.25	4.00
Tasks designed to assess the knowledge component required a deep understanding of the subject matter, rather than simply reproducing pre-established solutions.	3.63	4.00	0.59	3	5	3.00	4.00
The assessment prompted me to engage in critical thinking and identify optimal data processing methodologies independently.	3.58	4.00	0.61	3	5	3.00	4.00
The forms of final control, which included tests, projects, and reports, corresponded to the course content and served to evaluate the students' acquired skills.	4.16	4.00	0.50	3	5	4.00	4.00
In summary, I am happy with the way this course was organized and taught.	3.84	4.00	0.69	3	5	3.00	4.00
It is therefore recommended that this course be considered by other students who wish to acquire proficiency in Python for the purpose of conducting physics research.	4.00	4.00	0.75	3	5	3.25	4.75
It is my conviction that the time and effort allocated to this course was commensurate with my expectations.	4.21	4.00	0.71	3	5	4.00	5.00

Generalized descriptive statistics by CEQ scale are presented in table 3.

The results of the statistical analysis of the five main scales of the CEQ questionnaire show important patterns in the evaluation of different aspects of the course “Python for Physics Teachers”. The highest scores are observed for the “Clarity of goals and standards” scale with a mean of 4.30 and a relatively low standard deviation of 0.62, indicating that the course requirements are consistent and clear to students. It is important to note that the minimum score for this scale is 3 and the first quartile is 4.00, indicating that there are no low scores and that students are generally satisfied with this aspect of the course.

Table 3. Descriptive statistics by CEQ questionnaire scales.

Scales	Mean	Median	Standard deviation	Min	Max	Q1	Q3
I. Quality of teaching	4.10	4.00	0.71	1	5	3.75	5.00
II. Clarity of goals and standards	4.30	4.00	0.62	3	5	4.00	5.00
III. Practical orientation	4.20	4.00	0.58	3	5	4.00	5.00
IV. Appropriate assessment	3.80	4.00	0.65	3	5	3.00	4.00
V. Overall satisfaction	4.00	4.00	0.69	3	5	3.00	4.75

The “Practical orientation” scale ranks second in terms of mean (4.20) and has the lowest standard deviation (0.58) of all scales, indicating the greatest consistency in students’ opinions about the practical value of the course. This result is also confirmed by the high first quartile (4.00), which coincides with the median, indicating a concentration of ratings at the top of the scale.

The quality of teaching received an average score of 4.10, but has the largest range of scores from 1 to 5 and a relatively high standard deviation (0.71), which may indicate the heterogeneity of the students’ experiences in interacting with teachers. The first quartile of 3.75 and the third quartile of 5.00 further confirm the significant variability of scores in this category.

The lowest scores are observed on the assessment scale with an average of 3.80 points. It should be noted that the median (4.00) is higher than the mean, and the first quartile is 3.00, indicating a certain asymmetry in the distribution of grades towards lower values. Such results may indicate the need to improve the course evaluation system.

The overall satisfaction scale shows balanced results with a mean and median of 4.00 points. The standard deviation of 0.69 and the relatively wide interquartile range (3.00 to 4.75) indicate a variety of students’ overall impressions of the course, although the minimum score of 3 indicates that there are no extremely negative ratings.

Overall, the analysis of the statistical indicators indicates a high quality of course organization, especially in terms of clarity of objectives and practical focus, while also pointing to potential areas for improvement, particularly in the assessment system and consistency of teaching quality.

The analysis of the descriptive statistics shows that the “Python for Physics Teachers” course was generally successful, especially in terms of the structuring of the material and the practical orientation of the training. Clearly defined objectives and expected learning outcomes, together with a high rating of the practical component, indicate a well-designed course architecture. At the same time, there is a need to improve the assessment system and strengthen mechanisms to encourage student participation. The relatively high variability of grades in some aspects may indicate the need for a more individualized approach to teaching and taking into account different levels of student learning.

The study conducted a correlation analysis of the relationships between the five scales of the questionnaire using Spearman’s correlation coefficient (table 4).

The results of the correlation analysis revealed several statistically significant relationships between different scales of the questionnaire. The most significant correlations are observed between the following scales:

The “Quality of teaching” and “Overall satisfaction” show a strong positive correlation ($\rho = 0.812, p < 0.001$). This indicates that high quality teaching has a significant impact on students’ overall satisfaction with the course.

“Practical orientation” and “Clarity of goals and standards” also show a significant positive

Table 4. Correlation matrix.

Scale	Quality of teaching	Clarity of goals and standards	Practical orientation	Appropriate assessment	Overall satisfaction
Quality of teaching	1.000	0.745**	0.703**	0.673**	0.812***
Clarity of goals and standards	0.745**	1.000	0.785***	0.642**	0.734**
Practical orientation	0.703**	0.785***	1.000	0.658**	0.791***
Appropriate assessment	0.673**	0.642**	0.658**	1.000	0.687**
Overall satisfaction	0.812***	0.734**	0.791***	0.687**	1.000

Notes:*** $p < 0.001$ (very high statistical significance)** $p < 0.01$ (high statistical significance)* $p < 0.05$ (statistical significance)

relationship ($\rho = 0.785, p < 0.001$), indicating the importance of clear objectives for effective learning of practical skills.

“Appropriate assessment” has a moderate positive relationship with “Quality of teaching” ($\rho = 0.673, p < 0.01$), highlighting the relationship between teaching methods and the assessment system.

“Overall satisfaction” shows significant correlations with all other scales of the questionnaire, with the strongest relationship with “Quality of teaching” and “Practical orientation” ($\rho = 0.791, p < 0.001$).

The identified correlations indicate the complex nature of the students’ perceptions of the course. Of particular importance is the close relationship between teaching quality and overall satisfaction, which confirms the key role of the teacher in ensuring the effectiveness of the learning process.

The strong correlation between practical orientation and clarity of objectives indicates the importance of clearly structuring the course and defining its practical outcomes. This is especially true for a course aimed at developing practical programming skills in the context of a physical experiment.

Moderate correlations between the grading system and other scales indicate that the assessment is balanced and integrated into the overall structure of the course.

Based on the identified correlations, it is necessary to maintain a clear link between the theoretical objectives and the practical component of the course, ensuring the transparency of the requirements and expected learning outcomes. Attention should be paid to maintaining a balance between the different components of the course, taking into account their mutual influence on the overall effectiveness of the learning process.

5. Discussion

The results of the implementation of the course “Python for Physics Teachers” show its significant positive impact on the training of future teachers. The students noted the high quality of the teaching, the clarity of the goals, and the practical orientation of the course, which is consistent with current trends in education. The use of Python programming language in physics education promotes a deeper understanding of complex physical concepts through modeling and visualization. In particular, Python provides powerful tools for numerical solution of differential equations, optimization, and signal analysis, which are integral parts of physical research [25].

Research confirms that integrating Python into physics education not only improves understanding of the material, but also develops data science and programming skills that are critical in today’s digital society.

The students noted the high quality of the teaching, the clarity of the goals, and the practical orientation of the course, which is consistent with current trends in education. The practical focus was achieved through the execution of specific tasks that were directly associated with the domain of school physics. For instance, students developed programs to process data from kinematics laboratory experiments, created visualizations of projectile motion using Matplotlib, employed VPython to animate pendulum oscillations, and modeled transient processes in simple RC circuits. The final projects often assumed the guise of interactive simulations conceived for integration within the educational curriculum, accentuating the linkage to prospective professional pursuits. This approach has engendered a more profound comprehension of intricate physical concepts through modeling and visualization techniques. Moreover, it has been shown to promote the cultivation of data science and programming competencies, which are paramount in the current digital era.

In addition, the introduction of digital technologies in physics education, in particular the use of Python, is in line with modern educational standards and contributes to the development of key scientific skills in students.

However, to maximize the effectiveness of the course, it is necessary to take into account the individual needs of the students and provide additional support to those who may have difficulty learning programming. In general, the results of the study confirm the feasibility and effectiveness of integrating Python into the education of physics teachers, which is in line with current educational trends and the needs of the digital society.

6. Limitations

The study has several limitations that should be considered when interpreting the results. The small sample size of 19 students limits the statistical power of the analysis and the generalizability of the findings to a wider audience. Furthermore, conducting the study in an educational institution limits the external validity, as the specifics of the educational environment may be different in other institutions. The absence of an analysis of the long-term impact of the course on graduates’ professional activities also leaves open the question of the sustainability of the knowledge and skills acquired in real teaching practice.

Taking these limitations into account is important to interpret the results of the study and to plan future research initiatives in this area.

7. Conclusions

The results of the study confirm the feasibility of integrating the “Python for Physics Teachers” into the educational process of training future teachers. Analysis of the data and the students’ feedback allowed us to formulate the following main conclusions.

The course proved to be an effective tool for developing students’ basic programming and modeling skills in physical phenomena. It contributed to a deeper understanding of complex

physical concepts through their numerical modeling and visualization. The students commented on the high quality of the teaching, the clarity of the objectives, and the practical orientation of the course, indicating that the course content meets modern educational standards.

The use of Python in physics experiments and projects has created opportunities for students to develop the skills necessary for their future professional activities. Practical tasks that model real-life situations helped students see how programming can become an integrated tool in physics education at school. This is in line with modern STEM education trends that emphasize an interdisciplinary approach.

The course significantly increased the students' motivation to learn programming by showing them the practical relevance of Python in their professional activities. This is confirmed by the high scores on the scales of overall satisfaction and practical orientation in the CEQ questionnaire. At the same time, there were some difficulties for students with no previous programming experience, indicating the need for additional support for such participants.

The methodology of the course, based on the analysis of scientific research and practical recommendations, ensured its effectiveness. The use of the adapted CEQ questionnaire provided reliable data on the quality of teaching, assessment, and overall effectiveness of the course. Analysis of the results indicates a positive correlation between the clarity of the course objectives and student satisfaction.

Further research could focus on long-term monitoring of the impact of the course on graduates' teaching practice. Including a larger sample of respondents and conducting a comparative analysis in different educational institutions will help increase the validity of the results. Additionally, it is recommended to develop special adaptation measures for students without prior programming experience.

The introduction of the course "Python for Physics Teachers" was an important step in the modernization of the educational process, contributing to the training of competitive teachers who are able to use modern digital technologies in teaching. The results obtained indicate its significant potential for integration into teacher education and recommend its further implementation and improvement.

Conflicts of interest

The authors declares that there is no conflict of interest regarding the publication of this paper.

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Implementation of a competency-based approach in teaching astrophysics and astronomy

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Abstract. The article considers implementing a competency-based approach in teaching astronomy and astrophysics in general and specialised educational institutions. competency-based learning facilitates not only knowledge acquisition but also the development of key skills, including critical thinking, research and digital competencies, analytical abilities, communication skills, and teamwork. Special attention is given to the use of interactive technologies, particularly virtual laboratories, simulations, and digital tools, which enable students to observe and analyse astronomical phenomena even remotely. Programmes such as Stellarium, Universe Sandbox 2, and others open up opportunities for a deeper understanding of complex astronomical processes and contribute to the formation of students' scientific worldviews. The article also examines methods of organising laboratory work and research projects aimed at modelling cosmic phenomena, analysing the physical characteristics of stars, and calculating planetary orbits. The use of modern technologies in teaching allows for high-quality material assimilation, increased student motivation, and the integration of interdisciplinary knowledge. The research results confirm the effectiveness of the competency-based approach, which ensures the development of necessary skills for successful student adaptation to modern technological society and their preparation for further scientific or professional activities.

1. Introduction

Contemporary educational discourse increasingly frames effectiveness through the lens of competence formation, recognizing that successful adaptation to modern society requires more than theoretical knowledge alone [1–6]. The educational process must cultivate competencies that enable graduates to meet labor market demands, solve real-world problems, and realize their potential in both professional activities and social life. This paradigm shift represents a fundamental reimagining of educational goals and methodologies.

Astronomy occupies a unique position within this educational landscape, serving as a catalyst for comprehensive student development and scientific worldview formation [7, 8]. As a discipline that inherently bridges multiple scientific domains, astronomy naturally facilitates the integration of knowledge from physics, mathematics, chemistry, and even philosophy. The implementation of problem-oriented tasks combined with modern digital technologies provides students with a comprehensive understanding of astronomical phenomena while simultaneously developing their natural-mathematical worldview. This multifaceted approach significantly enhances the efficiency of the educational process, allowing students to engage in authentic research and observational activities even in remote learning environments.



The competency-based approach to astronomy education fundamentally reorients the learning process toward practical application rather than mere knowledge accumulation. Students develop abilities to apply theoretical understanding in real-world situations, transforming abstract concepts into practical skills. The relevance of this approach has become particularly evident in recent years, as astronomy education increasingly contributes to the development of both general and specialized competencies while preparing young people to work with cutting-edge technologies. The purpose of this work is to examine the implementation of a competency-based approach in astronomy education through practical tasks and projects, ultimately improving educational quality and student preparedness for future challenges.

This study employs a qualitative methodological framework to investigate the implementation strategies and outcomes. Our research methods encompass content analysis of current curricula and educational standards, expert review of developed astronomy lesson plans, and systematic comparison with international best practices. Data sources include official documents from the Ministry of Education alongside practical materials piloted in teacher training courses, providing a comprehensive view of both policy and practice.

2. Literature review

The competency-based approach has emerged as a cornerstone of educational modernization, attracting significant attention from researchers across diverse national contexts. Ukrainian scholars, including Bibik [9–11], Pometun [12], and Andryushchenko [13], have extensively explored the theoretical foundations and practical implications of this approach. Their work emphasizes the critical importance of knowledge integration across disciplinary boundaries, conceptualizing education as both a tool for social adaptation and a vehicle for personal development. International researchers such as Guthrie [14] and Henri et al. [15] have similarly contributed to this discourse, though significant aspects of competency-based learning, particularly assessment methodologies, remain subjects of ongoing investigation.

Within the Ukrainian context, researchers have undertaken comparative analyses between competency-based and traditional knowledge-based approaches. Zablotska [16], Lebedenko [17], and Sidun [18] have examined these distinctions, while Krichker and Yeremeieva [19], and Mateyuk [20] have investigated the educational technologies that facilitate competency development. These studies collectively demonstrate a growing consensus regarding the transformative potential of competency-based education.

International scholarship has further enriched our understanding of competency-based education. Leutner et al. [21] have contributed significant theoretical and empirical insights into the nature of competence and its development. Their work suggests that competency-based education enables learners not only to achieve intermediate educational or professional milestones but also to define and pursue meaningful life goals at personal and value levels. This becomes possible through the integration of educational competence frameworks with individual opportunities for lifelong learning [22].

Theoretical conceptualizations of competence vary across scholars yet maintain core commonalities. Marushchak [23] defines competence as an integrated ability encompassing knowledge, skills, personal qualities, and values that enable successful activity performance. Tkachov [24] emphasizes the readiness dimension, viewing competence as the capacity to apply knowledge, skills, and abilities effectively in professional contexts. Synthesizing these perspectives, competence emerges as a dynamic combination of knowledge, skills, practical abilities, thinking methods, professional qualities, and moral-ethical values that collectively determine one's capacity for successful professional and educational activities.

Recent developments in astronomy education research have increasingly focused on competency-based approaches. Over the past five years, scholars have explored personalized learning pathways, authentic assessment strategies, and the integration of digital tools including

virtual and augmented reality technologies. Dantic [25], Gervais [26], and Ye and Xu [27] have documented the development of transdisciplinary skills through astronomy education, demonstrating its potential to foster complex competencies that transcend traditional subject boundaries.

3. Theoretical framework

The practical implementation of the competency-based approach necessitates fundamental shifts in pedagogical methodology. Educational processes increasingly emphasize interdisciplinarity and the cultivation of research and communication skills, moving beyond traditional content delivery models. The integration of interactive methods, educational projects, and interdisciplinary lessons contributes not merely to knowledge acquisition but to the formation of value orientations and practical capabilities that prepare students for complex real-world challenges.

Competence development is intrinsically linked to self-development, which has emerged as a central element in contemporary lifelong learning paradigms. Through competency-based approaches, students develop not only domain-specific knowledge but also metacognitive skills essential for adaptation to evolving societal challenges. This educational philosophy prioritizes the development of self-assessment capabilities, reflective practices, and awareness of education's role in personal development trajectories. The cultivation of these metacognitive competencies enables learners to become autonomous agents in their own educational journeys, capable of identifying learning needs and pursuing appropriate developmental opportunities throughout their lives.

The Ukrainian legislative framework provides clear guidance on competency development. According to the Law of Ukraine "On Education" [28], key competencies encompass civic, mathematical, scientific, and digital domains, among others. General competencies refer to cross-disciplinary skills including critical thinking, communication, and learning to learn. Within astronomy education specifically, special competencies involve the ability to explain celestial phenomena, analyze observational data, and apply scientific models to understand cosmic processes. This tripartite framework of key, general, and special competencies provides a comprehensive structure for educational design and assessment.

Both international and domestic educational theorists correctly observe that key competencies are inherently dynamic, possessing variable structures that respond to societal priorities, educational goals, and opportunities for personal self-determination. The competency-based approach fundamentally orients education toward developing individuals capable of autonomous decision-making, adaptation to change, and realization of personal potential. This educational philosophy has become integral to modern pedagogical practice, aimed simultaneously at societal development and individual student success [19, 29].

The theoretical principles underpinning competency-based education form a coherent framework that guides practical implementation. Central to this framework is the focus on measurable learning outcomes expressed through specific competency development rather than mere knowledge accumulation. This results-oriented approach ensures that students master not only content but also the skills and abilities necessary for practical application in authentic contexts. The integration of knowledge, skills, and abilities represents another fundamental principle, enabling students to synthesize learning across domains and apply it effectively in varied contexts. This comprehensive approach fosters critical thinking, creativity, and complex problem-solving capabilities essential for professional and personal success.

Relevance and realism constitute critical dimensions of competency-based education. Learning experiences are deliberately grounded in real-world situations and authentic tasks, enabling students to develop problem-solving capabilities directly applicable to professional and personal contexts. This practical orientation manifests through active student participation in projects,

research initiatives, case studies, and hands-on tasks that provide experiential learning opportunities. Such engagement promotes the development of professional competencies while simultaneously fostering independence and collaborative skills essential for modern workplace success.

Flexibility and adaptability emerge as essential characteristics of competency-based educational systems. Educational processes must respond dynamically to individual student needs while maintaining responsiveness to evolving social and professional environments. This adaptability ensures that learners can continuously update their knowledge and skills throughout their careers, embodying the principle of lifelong learning. The interdisciplinary nature of competency-based education further enhances its effectiveness by facilitating knowledge integration across traditional disciplinary boundaries. Students develop the capacity to recognize interconnections between different fields of knowledge, applying integrated understanding to complex interdisciplinary challenges.

Individualization represents another cornerstone principle, acknowledging that each student brings unique needs, capabilities, and interests to the learning environment. Competency-based approaches enable the creation of personalized educational trajectories that optimize individual competency development. This personalization is complemented by systematic reflection and self-assessment practices that develop students' metacognitive abilities. Through regular engagement in self-evaluation, learners develop self-control and self-regulation skills, enabling them to identify areas for improvement and take ownership of their learning progress.

Finally, the principles of cooperation and communication underscore the social dimension of competency development. Modern educational environments must cultivate teamwork capabilities, effective communication skills, and collaborative problem-solving abilities. These interpersonal competencies prove essential for successful socialization and professional effectiveness in increasingly interconnected and team-based work environments. Together, these principles create a comprehensive framework that prepares individuals not merely to possess knowledge but to apply it effectively in solving real-world problems, working collaboratively, and adapting to the dynamic demands of contemporary professional and social life.

4. Competency-based teaching of astronomy

The implementation of competency-based approaches in astronomy education transcends traditional knowledge transmission, fostering the development of critical skills that enable students to become engaged and informed citizens [30, 31]. Astronomy's inherently interdisciplinary nature positions it as an exceptional vehicle for developing key learning competencies, as it seamlessly integrates diverse knowledge domains, stimulates research activities, and cultivates scientific curiosity.

Contemporary state standards and curricula emphasize the development of multiple interconnected competencies through astronomy education. Natural science competence emerges through students' engagement with fundamental physical laws that govern celestial phenomena. When investigating lunar phases or planetary motion, students master gravitational principles and universal structures, developing deep conceptual understanding. Practical activities such as stellar spectra analysis, variable star light curve examination, and solar activity observation cultivate experimental skills alongside data collection and processing capabilities. These experiences provide students with authentic scientific practice that mirrors professional astronomical research.

Mathematical competence develops organically through astronomy's quantitative dimensions. Students engage with mathematical models and calculations to determine planetary orbits using Kepler's laws, compute stellar photometric parameters, calculate celestial body velocities, and determine stellar distances through trigonometric parallax methods. Working with spherical coordinate systems and solving complex astronomical problems requires sophisticated

mathematical reasoning, demonstrating the practical application of mathematical concepts in scientific contexts. This integration of mathematics with physical phenomena helps students appreciate mathematics as a tool for understanding nature rather than an abstract discipline.

Digital competence [32] has become increasingly central to modern astronomy education. Software platforms including Stellarium, Celestia, World Wide Telescope, and Universe Sandbox 2 enable students to model astronomical phenomena with unprecedented accuracy and detail. Access to professional astronomical databases such as Simbad and the NASA Exoplanet Archive develops students' abilities to work with large-scale data sets, fostering information literacy and computational thinking skills. These digital tools democratize access to astronomical research, allowing students to engage with real scientific data regardless of their geographic location or institutional resources.

Analytical competence develops through systematic engagement with complex astronomical problems that require critical thinking and evidence-based reasoning. Analyzing stellar spectra or evaluating theories of universal origin demands that students assess information reliability, test hypotheses, and construct logical arguments. This analytical rigor extends beyond astronomy, preparing students to evaluate claims critically and think scientifically about diverse phenomena. Research competence is reinforced through project-based learning where students investigate variable stars, analyze exoplanet motion, or conduct other authentic research activities. These projects develop skills in hypothesis formulation, research design, data analysis, and scientific communication.

Communication competence flourishes through collaborative activities and scientific discourse. Participation in discussions, debates, scientific conferences, and group projects develops students' abilities to articulate complex ideas clearly and persuasively. Collaborative research projects, planetary system modeling, mission planning exercises, and observational presentations foster effective communication while promoting socialization and teamwork skills. These experiences prepare students for the collaborative nature of modern scientific research and professional work environments.

Environmental literacy emerges through consideration of space's relationship with Earth's biosphere. Discussions addressing space debris, rocket launch environmental impacts, and planetary colonization possibilities develop students' understanding of humanity's environmental responsibilities beyond Earth. This cosmic perspective enhances appreciation for Earth's uniqueness while fostering global environmental consciousness. Creative and innovative thinking manifests through original project development, celestial mechanics modeling, and novel observational method design. Such activities cultivate non-standard thinking approaches and creative problem-solving capabilities essential for scientific advancement.

Ethical competence develops through thoughtful consideration of space exploration's moral dimensions. Discussions exploring humanity's responsibilities in cosmic research and space resource utilization raise profound ethical questions about our role in the universe. Examining contributions from scientists across different eras and cultures helps students understand science as a global human endeavor, fostering appreciation for diverse perspectives and international collaboration.

Beyond these general competencies, astronomy education cultivates specialized skills unique to the discipline. Students develop comprehensive knowledge of astronomical phenomena and laws, gaining deep understanding of the physical processes governing cosmic evolution. Observational skills are honed through telescope use and celestial object identification, whether through direct observation or virtual platforms. Data analysis capabilities develop through working with astronomical instruments and interpreting observational results. Perhaps most distinctively, astronomy education enhances spatial thinking abilities essential for comprehending the universe's three-dimensional structures and vast scales.

The integration of these diverse competencies through astronomy education creates a powerful

educational synergy. Rather than developing skills in isolation, students experience how different competencies interconnect and reinforce each other. Mathematical skills support data analysis, digital tools enable research, communication skills facilitate collaboration, and ethical considerations guide scientific practice. This holistic approach prepares students not merely to understand astronomical concepts but to engage meaningfully with scientific and technological challenges throughout their lives.

5. Assessment system within the competency-based approach

The competency-based approach fundamentally transforms assessment practices in astronomy education, moving beyond traditional knowledge testing to evaluate students' ability to apply understanding in practical contexts. This comprehensive assessment framework encompasses both formative and summative dimensions, each serving distinct yet complementary purposes in supporting student development.

Formative assessment has emerged as a crucial mechanism for tracking competency development throughout the learning process. Rather than merely checking factual recall, formative assessment in astronomy education evaluates how students integrate knowledge, skills, and dispositions to engage with astronomical phenomena. This ongoing assessment provides continuous feedback that guides both teaching and learning, creating a dynamic educational environment responsive to student needs.

Oral assessment methods offer rich opportunities to evaluate multiple competencies simultaneously. When students engage in discussions about astronomical phenomena such as dark matter's nature, teachers assess not only conceptual understanding but also argumentation skills, scientific vocabulary use, and receptiveness to alternative viewpoints. The quality of reasoning, evidence presentation, and respectful engagement with peers' ideas all provide insights into competency development. Problem-based questioning that elicits collective responses reveals students' abilities to synthesize knowledge collaboratively, search for information effectively, and construct reasoned explanations. For instance, when posed with questions about determining stellar composition, students demonstrate their capacity to integrate spectroscopy concepts, apply analytical reasoning, and communicate scientific ideas clearly.

Short presentations on astronomical topics provide windows into multiple competency domains. As students present findings about exoplanet discoveries or other current astronomical research, teachers evaluate information structuring, visual communication effectiveness, and responsiveness to audience questions. These presentations reveal not only content mastery but also digital literacy, communication skills, and ability to engage with scientific literature.

Written assessment methods, particularly those emphasizing process over product, offer valuable insights into student thinking and competency development. Observation logbooks maintained during real or virtual celestial observations document students' attention to detail, recording accuracy, and ability to draw preliminary conclusions from data. These records provide authentic evidence of scientific practice skills developing over time. Concept mapping exercises, where students explore relationships between astronomical concepts, reveal depth of understanding and ability to recognize connections across topics. When students create concept maps centered on terms like "black hole", the richness and accuracy of their connections indicate conceptual understanding depth.

Reflective writing exercises encourage metacognitive development while providing assessment data. When students respond to prompts about their learning experiences, challenges encountered, and strategies for improvement, they develop self-awareness while providing teachers with insights into their learning processes. This metacognitive dimension proves essential for developing autonomous learners capable of directing their own educational growth.

Practical assessment methods directly evaluate students' abilities to apply knowledge in authentic contexts. Modeling activities, where students create scale representations of solar

systems or eclipse mechanisms, demonstrate understanding of spatial relationships, mathematical scaling, and physical principles. The accuracy of models, appropriate simplifications made, and explanations provided all offer assessment evidence. Working with astronomical software and star charts assesses digital competency, spatial reasoning, and ability to navigate information systems. Tasks requiring students to locate celestial objects, determine coordinates, or predict celestial events provide authentic performance assessments aligned with real astronomical practice.

Mini-projects integrate multiple competencies in extended performance tasks. Whether researching light pollution impacts, creating presentations on telescope history, or conducting other investigations, these projects reveal students' abilities to plan work, collaborate effectively, search and analyze information, and produce meaningful products. The project process and outcomes both provide rich assessment data about competency development across multiple domains.

Self and peer assessment methods develop evaluative judgment while distributing assessment responsibility. When students assess their own laboratory work against clear criteria, they develop critical evaluation skills and ownership of learning. Peer assessment of presentations using structured rubrics develops students' abilities to provide constructive feedback while reinforcing quality criteria. These participatory assessment approaches foster assessment literacy, helping students understand and internalize performance standards.

The integration of diverse assessment methods creates a comprehensive picture of student competency development. Rather than relying on single assessment events, this multifaceted approach captures the complexity of competency-based learning. Teachers gather evidence from multiple sources over time, building rich profiles of student capabilities and growth trajectories. This assessment diversity also accommodates different student strengths, ensuring that various competencies are recognized and valued.

Importantly, assessment within the competency-based framework serves primarily formative purposes, providing feedback to enhance learning rather than merely sorting or ranking students. The emphasis shifts from comparative evaluation to criterion-referenced assessment focused on competency development. This approach creates more supportive learning environments where assessment becomes a tool for growth rather than judgment. Through systematic implementation of these varied assessment strategies, astronomy educators can effectively monitor and support the complex competency development that modern education demands.

6. Practical classes in astronomy for the development of general competencies

Modern competency-based astronomy education emphasizes practical application of theoretical knowledge through hands-on experiences that prepare students for scientific and technological careers. Contemporary educational resources expand learning possibilities beyond traditional classroom boundaries, enabling students to engage with authentic astronomical data and phenomena. The integration of digital tools such as Stellarium, Celestia, WorldWideTelescope, Universe Sandbox, and Star Walk transforms abstract concepts into tangible experiences, while project-based learning promotes interdisciplinary knowledge integration and independent analytical thinking.

Research competencies form the foundation of scientific literacy, encompassing hypothesis formulation, methodological selection and application, data analysis, and critical interpretation of results [33]. These skills prove particularly crucial in astronomy, where direct experimentation is often impossible and students must rely on observational data and modeling. The adaptation to distance learning environments has accelerated the integration of digital technologies, with simulators, mobile applications, and virtual observatories enabling students to model astronomical phenomena and conduct virtual observations from any location [34].

Laboratory classes serve as crucial venues for competency development, providing structured opportunities for students to engage with scientific practices. Through these experiences,

students develop research skills including data analysis, graphing, and conclusion formulation. The problem-solving inherent in laboratory work fosters critical thinking and analytical reasoning. Students gain proficiency with modern technologies, from telescope operation to digital simulation platforms, while collaborative laboratory activities develop communication and cooperation skills essential for scientific teamwork.

The design of effective laboratory experiences in astronomy requires careful consideration of both content and process. For instance, investigating apparent celestial motion using Stellarium allows students to observe and analyze stellar, planetary, and lunar movements across different temporal scales. Students can track trajectories, determine sunrise and sunset times throughout the year, and create graphical representations of solar altitude variations. Such activities develop observational skills, data visualization capabilities, and understanding of Earth's relationship with celestial bodies.

Lunar phase investigations exemplify how simple observations can yield profound understanding. Whether through direct observation or simulation, students document lunar changes over monthly cycles, analyze patterns, and explain the geometric relationships causing phase variations. This extended observational project develops patience, systematic recording skills, and ability to connect observations with theoretical models. Similarly, planetary position determination using virtual planetaria enables students to explore solar system dynamics, create star charts, and understand apparent planetary motion [35].

Eclipse studies through platforms like Celestia allow students to model these spectacular phenomena, exploring their causes, characteristics, and predictability. By manipulating variables and observing outcomes, students develop intuitive understanding of the three-dimensional celestial mechanics underlying eclipses. Angular size measurements, whether conducted with simple tools or simulations, introduce concepts of celestial distance and scale while developing measurement skills and mathematical reasoning.

More advanced laboratory work engages students with professional astronomical practices. Constructing Hertzsprung-Russell diagrams from stellar data introduces fundamental concepts of stellar evolution while developing data analysis and visualization skills [36]. Investigating Kepler's laws through simulations enables students to explore planetary motion principles, analyze orbital parameters, and understand the mathematical relationships governing celestial mechanics [37]. Spectral analysis activities using databases like the NASA Exoplanet Archive introduce students to how astronomers determine stellar properties from light alone [38].

Variable star analysis represents authentic research that students can conduct using professional databases. Working with resources like SIMBAD, students observe brightness variations, construct light curves, and investigate variability causes [39]. This work mirrors professional astronomical research, providing students with genuine scientific experience. Modeling cosmic phenomena through platforms like PhET Interactive Simulations allows exploration of gravitational interactions, orbital dynamics, and celestial collisions, developing intuitive understanding of fundamental physical principles [37].

The integration of these diverse laboratory experiences creates a comprehensive practical education that complements theoretical instruction. Students develop not only specific astronomical knowledge but also transferable scientific skills applicable across disciplines. Data analysis capabilities, computational thinking, experimental design skills, and scientific communication abilities all transfer to other scientific domains and professional contexts.

Distance learning adaptations have demonstrated that effective practical astronomy education need not require physical laboratory spaces or expensive equipment. Digital tools democratize access to astronomical experiences, allowing students anywhere to engage with the same data and phenomena studied by professional astronomers. Project tasks analyzing open database information or investigating phenomena like day length variations promote independent research skills while maintaining scientific rigor.

Through systematic engagement with these practical activities, students develop the complex competency profiles demanded by modern STEM fields. They learn to navigate large datasets, use sophisticated analysis tools, collaborate effectively, and communicate findings clearly. These experiences prepare them not merely to understand astronomy but to participate in scientific endeavors, whether as future professionals or scientifically literate citizens. The practical dimension of astronomy education thus proves essential for developing the full spectrum of competencies required for success in our increasingly technological society.

7. Examples of lesson development incorporating the competency-based approach

The integration of information and communication technologies in astronomy education enables students to engage with authentic astronomical data while developing critical research skills. Simulations provide opportunities to explore astronomical phenomena even without specialized equipment, simultaneously fostering technical literacy and analytical thinking. The following detailed lesson example illustrates how competency-based principles translate into practical classroom implementation.

Consider a lesson focused on studying the apparent motion of celestial bodies, designed to achieve multiple learning objectives while developing various competencies. The lesson aims to familiarize students with apparent celestial motion concepts, develop skills in astronomical simulator use, and foster analytical thinking through observation and conclusion drawing. Expected outcomes include mastery of apparent motion concepts, proficiency with Stellarium software, successful observation of solar, lunar, and stellar apparent motion, and creation of graphical representations showing solar altitude variations across seasons.

The lesson begins with motivational questions that connect astronomical concepts to everyday experience. For instance, exploring why the Sun rises and sets at different horizon points throughout the year leads naturally into discussions of Earth's axial tilt and orbital motion. Students discover that summer sunrise and sunset points lie further north than winter ones, while equinox positions align with true east and west. This introductory discussion demonstrates how apparent celestial motion observations enable temporal and spatial orientation, connecting ancient navigation practices with modern understanding. Historical examples, such as using the North Star for navigation or seasonal constellation patterns for agricultural timing, illustrate astronomy's practical applications throughout human history.

The main instructional phase involves structured investigation using digital tools. Students work collaboratively in small groups via video conferences, with each group assigned different celestial objects for observation. This differentiation ensures comprehensive coverage while promoting peer learning through subsequent presentations. The first task requires investigating selected objects' daily motion patterns. Using Stellarium, students set their location, select specific dates such as solstices, and track their assigned celestial body throughout a simulated day. They record sunrise and sunset times, document altitude changes, and create graphical representations of daily motion patterns.

For example, students investigating solar motion in Kryvyi Rih on the winter solstice would observe sunrise at approximately 07:30 and sunset at 16:00, noting the Sun's low maximum altitude and southern trajectory. Comparing this with summer solstice observations reveals dramatic seasonal variations in day length and solar path, fostering understanding of Earth-Sun geometric relationships.

The second task extends investigation to coordinate determination and object property analysis. Students search for specific stars or planets using Stellarium's database, determine equatorial coordinates, and document physical properties including luminosity, temperature, and distance. This activity develops familiarity with astronomical coordinate systems while introducing concepts of stellar classification and properties. When studying Sirius, for instance, students discover its position at right ascension 06h 45m 08.9s and declination $-16^{\circ}42'58''$, while

learning about its remarkable luminosity of 25.4 solar luminosities, surface temperature of 9940 K, and proximity at 8.6 light-years distance.

Throughout these activities, students develop multiple competencies simultaneously. Digital competence emerges through software navigation and feature utilization. Mathematical skills develop through coordinate system work and graphical representation creation. Analytical thinking strengthens as students identify patterns and draw conclusions from observations. Communication skills grow through group collaboration and results presentation.

Another exemplary lesson addressing stellar properties and classification demonstrates how complex astronomical concepts can be taught through competency-based approaches. This lesson's objectives include developing astrophysical data analysis skills, understanding stellar physical parameters, working with Hertzsprung-Russell diagrams, and enhancing presentation abilities through results discussion.

The lesson structure involves dividing students into groups investigating different stellar categories: red giants, white dwarfs, supergiants, and main sequence stars (figure ??). Each group researches their assigned stellar class characteristics, including surface temperature, luminosity, size, and mass. Groups then position their stellar types on a class Hertzsprung-Russell diagram, either physical or digital, based on these properties. This hands-on approach transforms abstract concepts into concrete understanding through active engagement.

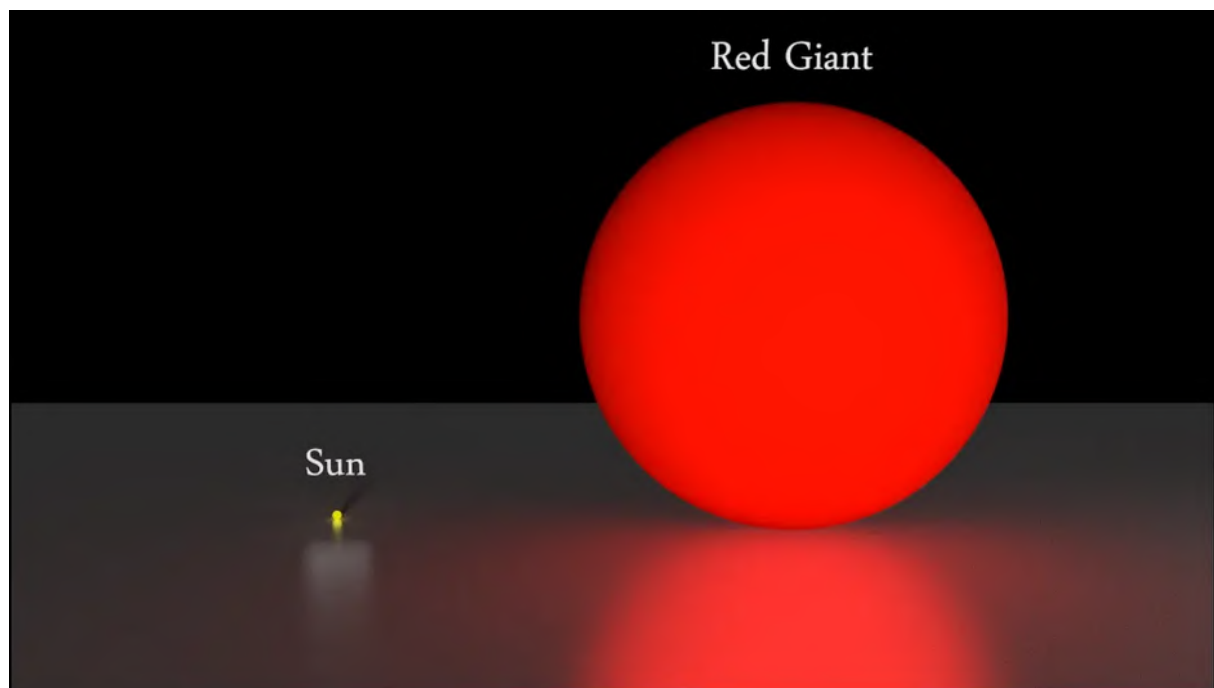


Figure 1. Comparison of the relative sizes of the Sun and a Red Giant star. The Sun, shown on the left, appears much smaller compared to the massive Red Giant on the right. This illustrates the significant increase in stellar radius that occurs when a main-sequence star like the Sun evolves into the red giant phase [41].

Red giant investigators, for example, discover surface temperatures between 3000-4000 K, luminosities 100-1000 times solar, radii 10-100 times larger than the Sun, yet masses comparable to solar values. Placing these stars in the diagram's upper right region, students understand how low temperature combined with high luminosity indicates enormous stellar size. Their presentation explains how red giants represent evolved stars that have exhausted core hydrogen,

expanded dramatically, and cooled to reddish temperatures while maintaining high luminosity through their enormous surface areas.

This lesson structure promotes deep conceptual understanding while developing presentation skills, analytical reasoning, and collaborative abilities. Students learn not merely stellar classification facts but understand the physical principles underlying stellar diversity. They practice scientific communication by explaining complex concepts to peers, developing skills essential for scientific careers.

These exemplary lessons demonstrate how competency-based approaches transform astronomy education from passive knowledge reception to active scientific engagement. Students develop authentic scientific practices, use professional tools, analyze real data, and communicate findings effectively. The integration of digital technologies enables experiences previously impossible in school settings, democratizing access to astronomical investigation. Through such carefully designed lessons, astronomy education fulfills its potential to develop scientifically literate, critically thinking, technologically capable citizens prepared for twenty-first-century challenges.

8. Results and discussion

The implementation of competency-based approaches in astronomy education yields compelling evidence of enhanced student engagement and skill development. Our findings demonstrate that astronomy's interdisciplinary nature provides an ideal context for integrating scientific, digital, and civic competencies in meaningful ways. Students engaging with astronomical phenomena through practical applications show marked improvement in critical thinking abilities, data analysis skills, and scientific reasoning compared to traditional instructional approaches.

These results align with European research advocating for authentic, inquiry-based learning in science education [25, 27]. However, astronomy presents unique cognitive demands that distinguish it from general science education. The discipline requires sophisticated spatial reasoning abilities to comprehend three-dimensional celestial mechanics and vast cosmic scales. Model-based reasoning proves essential for understanding phenomena that cannot be directly manipulated or experimentally controlled. These distinctive requirements necessitate explicit attention in curriculum design, ensuring that instructional approaches specifically develop these specialized cognitive capabilities alongside general scientific competencies.

The integration of digital tools has proven particularly transformative in developing student competencies. Virtual observatories and simulation software provide access to phenomena otherwise inaccessible to school-based observation, while databases of professional astronomical data enable authentic research experiences. Students using these tools demonstrate increased motivation and deeper conceptual understanding compared to traditional textbook-based instruction. The ability to manipulate variables, observe outcomes, and test hypotheses in virtual environments fosters intuitive understanding of complex astronomical principles that abstract descriptions alone cannot achieve.

Assessment data reveals that competency-based approaches successfully develop both domain-specific and transferable skills. Students show improvement not only in astronomical content knowledge but also in general scientific practices including hypothesis formation, data interpretation, and evidence-based argumentation. Communication competencies develop through collaborative projects and presentations, while digital literacy advances through engagement with professional astronomical software and databases. These multifaceted outcomes suggest that astronomy education contributes broadly to student preparation for STEM careers and scientifically informed citizenship.

Challenges in implementation primarily center on teacher preparation and resource availability. Effective competency-based astronomy education requires teachers comfortable with both astronomical content and diverse pedagogical approaches. Professional development

focusing on inquiry-based instruction, formative assessment strategies, and digital tool integration proves essential for successful implementation. Additionally, while digital tools democratize access to astronomical experiences, reliable internet connectivity and appropriate devices remain prerequisites that may limit implementation in under-resourced contexts.

9. Conclusion

The implementation of competency-based approaches in astrophysics education represents a fundamental advancement in contemporary pedagogical practice, fully aligned with the New Ukrainian School's educational philosophy. This comprehensive approach transcends traditional knowledge transmission, fostering the development of integrated competencies that encompass skills, abilities, and values essential for practical problem-solving and scientific literacy. Astronomy's unique position as an interdisciplinary science bridging physics, mathematics, computer science, and geography creates an optimal environment for competency-based learning implementation.

The advantages of this pedagogical approach manifest across multiple dimensions of student development. Active engagement through interactive and practical tasks transforms students from passive recipients to active constructors of knowledge, fostering deeper understanding and retention. Information literacy develops organically as students learn to navigate, analyze, interpret, and apply complex astronomical data in meaningful contexts. Environmental consciousness emerges through examination of space exploration's implications and humanity's cosmic responsibilities, cultivating global citizenship perspectives that extend beyond Earth. The integration of innovative methodologies, particularly STEM education approaches and interdisciplinary projects, sustains student motivation and interest in natural sciences, addressing concerns about declining science engagement among youth.

Modern digital tools have proven instrumental in realizing competency-based astronomy education's full potential. Platforms such as Stellarium, Star Walk, PhET simulations, and Universe Sandbox 2 provide unprecedented access to realistic observations and modeling capabilities, democratizing astronomical investigation regardless of geographic location or institutional resources. These tools enable students to engage with the same data and phenomena studied by professional astronomers, bridging the gap between school science and authentic scientific practice.

Laboratory work, projects, and research tasks targeting cosmic phenomena modeling, stellar property analysis, and planetary orbit calculations cultivate essential competencies for modern scientific engagement. Through these experiences, students develop research competence by learning to formulate testable hypotheses, select appropriate methodologies, and critically evaluate results. Critical thinking strengthens through engagement with complex problems requiring evidence evaluation and logical reasoning. Digital literacy advances through interaction with sophisticated software and databases, while independence grows through self-directed investigation and project management.

The competency-based approach's effectiveness in astronomy education extends beyond immediate learning outcomes, preparing students for lifelong learning and adaptation to rapidly evolving scientific and technological landscapes. Students develop metacognitive awareness that enables them to recognize learning needs, seek appropriate resources, and continuously update their understanding. The integration of reflection and self-assessment practices fosters autonomous learners capable of directing their own intellectual development throughout their careers.

This educational transformation carries implications for broader educational reform. Astronomy education's success in implementing competency-based approaches provides a model for other disciplines seeking to modernize pedagogical practices. The emphasis on authentic tasks, formative assessment, and digital tool integration offers transferable strategies applicable across

STEM fields and beyond. Furthermore, the development of scientific literacy through astronomy education contributes to societal goals of creating informed citizens capable of engaging with complex scientific and technological issues.

Looking forward, several areas warrant continued attention and development. Teacher professional development remains crucial for successful implementation, requiring ongoing support for educators adapting to new pedagogical approaches and technologies. Assessment methodologies require further refinement to capture the full complexity of competency development while maintaining practical feasibility for classroom implementation. Research into long-term impacts of competency-based astronomy education on student career trajectories and scientific engagement would provide valuable validation of these approaches.

The evidence presented throughout this work confirms that competency-based approaches in astronomy education contribute substantially to students' comprehensive development. The formation of essential skills and abilities prepares students not merely for academic success but for meaningful participation in contemporary society's scientific and technological dimensions. As education systems worldwide grapple with preparing students for uncertain futures, astronomy education's competency-based transformation offers valuable insights into creating learning experiences that develop adaptable, critically thinking, scientifically literate citizens ready to address tomorrow's challenges.

This educational evolution represents more than methodological change; it embodies a fundamental reconceptualization of education's purpose and potential. By fostering deep understanding alongside practical capabilities, competency-based astronomy education prepares students to navigate complexity, embrace lifelong learning, and contribute meaningfully to scientific and societal advancement. The successful implementation of these approaches in astronomy education thus serves as both achievement and inspiration, demonstrating education's transformative power when aligned with contemporary needs and possibilities.

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Instructional design for teaching analytical chemistry in English as a foreign language

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Abstract. The article summarises the experience of teaching analytical chemistry in English to Chinese first-year undergraduate students during 2019-2023. During this period, about 800 students with five years of enrollment in two specialities (biotechnology and chemical technology and engineering) were trained at Kyiv College of the Qilu University of Technology (China). The key problem of the initial stage of training in 2019-2020 was the contradiction between the gradual improvement of students' knowledge of the English language over the years of enrollment and the simultaneous deterioration of chemical knowledge. Teaching materials and teaching methods during the period were based on multimedia lecture courses at the Kyiv National University of Technology and Design. Curricula and programs remained unchanged throughout the studied period. The instructional design of lecture courses was gradually and purposefully optimised to eliminate the invented problems and minimise the negative impact of the pandemic (in the period 2020-2021 and partially 2022). The optimisation was based on the principles of the theory of cognitive load. Particular attention was paid to mastering chemical knowledge at the micro, macro and symbolic levels and forming connections between these three levels. The applied changes in educational materials stabilised examination results in analytical chemistry during the COVID-19 period and contributed to their improvement after quarantine.

1. Introduction

Modernisation of teaching methods of natural sciences, on the one hand, is a requirement of the time when new, often previously unknown tools and teaching aids are constantly emerging due to the development of information and communication technologies (ICT) [1]. On the other hand, traditional teaching problems (the right choice of pedagogical technology, ensuring individualisation of learning, rapid transition between offline and online teaching with appropriate resources, etc.) do not disappear automatically in the case of suboptimal use of new technologies. In some cases, they are even more acute. For example, when chemical disciplines are studied in parallel with ecology, pharmacy, and engineering, which are characterised by more complex interdisciplinary connections [2, 3]. Integration of border disciplines improves understanding and application of scientific concepts in different fields and develops critical thinking and problem-solving skills among students [4, 5].

Experience clearly shows that students perceive or do not perceive new ICT tools in learning in different ways [6]. Therefore, the use of new learning tools themselves does not lead to an



automatic improvement in its results [7]. The reason for this effect is not yet fully understood, so research on this issue remains relevant [8,9].

Several conditions seem necessary for the effective use of electronic resources, among which it is worth noting the choice of teaching methods and educational resources considering the audience's characteristics and the cognitive load caused by them [10]. Excessive load impairs understanding, and underload contributes to loss of attention [11,12]. Under such conditions, the principles of cognitive load theory (CLT) [13,14] increasingly play the role of a core that forms the key requirements for creating a successful instructional design using ICT tools.

Lectures remain the main form of organising teaching in fundamental natural disciplines. Although quite conservative, lectures in the era of ICT dominance have undergone significant changes, primarily caused by the widespread use of multimedia tools. Instead of lectures in the classical sense, multimedia lectures dominate, which have their patterns with corresponding advantages and limitations [15,16].

Among the consequences of introducing ICT methods is a significant expansion and facilitation of information search and exchange globalisation of the educational process. A separate and increasingly popular aspect of educational activity has become teaching in a foreign language, primarily English. This organisation of education is at the centre of this work. Along with undeniable advantages, teaching in a foreign language contributes to the emergence of additional cognitive load [17], associated with an extra expenditure of time and effort on mental translation/understanding of words and terms in both directions. At the same time, foreign teachers use the same formats and resources adopted in their country. Under such conditions, educational resources optimised for one audience can easily become suboptimal for a foreign language learning environment. They will contribute to cognitive overload and require optimisation of educational materials [18].

In work [19], an analysis of the problems that arise when teaching Chinese students specialising in chemical and biotechnology to chemical disciplines using English was initiated. The identified shortcomings in constructing educational materials for the learning conditions served as the basis for initiating instructional design optimisation. The purpose of this work was a detailed analysis of educational materials in analytical chemistry aimed at identifying problems that arise when teaching in English to Chinese students by teachers from Ukraine. The changing external conditions of the 2019-2023 academic years forced one to consider the impact of traditional and forced online learning conditions in the context of COVID-19. The data obtained, primarily the level of assimilation of chemical knowledge by students depending on the educational materials used, were used to optimise the package of educational presentations for teaching analytical chemistry in the following years.

2. Experimental

The results described in the paper were obtained during analytical chemistry teaching at Qilu University of Technology (Jinan City, Shandong Province, People's Republic of China) for five (2019-2023) years. Students of Kyiv College of Qilu University of Technology (KCQUT), citizens of China, study in English with the involvement of teachers from Kyiv National University of Technology and Design (KNUTD) according to the educational programs and agreed curricula of KNUTD.

In five early intakes, the study covered first-year students of two specialities, Biotechnology (BT) and Chemical Technology and Engineering (CTE). Each speciality had an average group of 78-80 students, i.e. over 5 academic years, the learning outcomes of about 800 first-year students of both specialities were assessed.

Analytical chemistry is one of the basic disciplines in the training of future engineers in the field of chemical and biotechnology. The course consisted of 16 lectures of 90 minutes each and was supplemented by laboratory classes, which were assessed separately. On average, the

materials of each lecture were presented in 55-70 information slides. All slides were developed in compliance with Mayer's multimedia principles [15], creating the prerequisites for optimal cognitive load of students [19].

The educational design of the educational materials was initially built following the format adopted at KNUTD, which has been used in recent years to teach students of various specialties of the Faculty of Chemical and Biopharmaceutical Technologies. A sufficient number of respondents and a five-year observation period allowed one to identify and classify shortcomings in the teaching methods introduced in the first year of the experiment based on the experience of KNUTD. The main drawback is the slowdown in progress in teaching chemistry with the years of enrollment. Learning outcomes were assessed based on the results of two midterm tests and a written final exam, which formed the overall average grade for the discipline on a 100-point scale.

COVID-19 affected the learning conditions. In 2020/21 and 2021/22, learning was conducted remotely online. Conversely, in 2019/20 and 2023/24, learning took place in the traditional classroom setting. The 2022/23 academic year should be considered transitional, as it contained both quarantine and traditional learning elements.

Based on the results of 2019, a gradual correction of the content of educational materials was initiated. The changes were implemented considering the principles and recommendations of the cognitive load theory [6, 20]. According to the classical version of this theory, cognitive load is divided into intrinsic, extraneous and germane. The total cognitive load is additive, equal to the sum of the specified types. However, additivity is preserved only in the absence of overload if the total load does not exceed the students' working memory capabilities.

Students' cognitive load levels were studied by the secondary task method. This method constructs a notable approach to measuring cognitive load, especially in educational and operational contexts [21]. According to this method, the student simultaneously performs two tasks, educational and secondary. The first is the main one and aims to study a certain fragment of chemical material, which can be presented in different formats (text, audio, video) or combined in different experiments. The second task involves performing certain actions simultaneously while continuing the educational task and requires the same cognitive resources. The productivity of performing the secondary task directly depends on the productivity of performing the main one. It allows researchers to assess the cognitive load imposed by the main task. It is believed that the longer the reaction time required to start performing the secondary task, the greater the cognitive load the respondent experiences from the primary task, depending on the format.

The effectiveness of this method is supported by various studies that highlight its sensitivity to different levels of cognitive load and its applicability in different areas [22]. However, the complexity of the primary task can affect the sensitivity of secondary tasks, potentially leading to variability in results. For example, more complex primary tasks may reduce the effectiveness of certain secondary measures [23]. Accordingly, alternative methods can still provide helpful additional information [24].

Details of the methodology of secondary tasks using home-made software are given in [25], along with the results of a study of the level of cognitive load experienced by Ukrainian students while studying educational chemistry material in various multimedia formats. For Chinese students, similar experiments were conducted episodically, when implementing the most important changes, and for separate samples of students. Where data was lacking, a simple questionnaire was given after the lecture in the form of an online form.

For example, the secondary task method helped to determine changes in cognitive load when studying one selected topic using slides of different structures. In the context of a general reduction in the number of slides, the main elements of their formatting (primarily font size and text density) remained unchanged. The reduction was achieved by eliminating auxiliary,

non-informative slides, reducing non-essential examples, and replacing texts with shorter ones or graphic illustrations.

As mentioned, cognitive load, depending on the form of presentation of the material for Chinese students, was studied in a limited cases due to the lack of time required to conduct extended studies. However, it should be noted that Chinese students demonstrate similar learning preferences to Ukrainian students of similar majors. It gives grounds to assume a similarity in the influence of the form of lecture fragments on cognitive load in most cases. Some differences may exist based on the peculiarities of non-native language teaching for Chinese students and slight differences in learning preferences revealed after several years of teaching. Thus, the patterns of the influence of the form of presentation of lecture material on the level of cognitive load invented in [25] were used in the current work.

Statistical processing of the obtained results was performed using the IBM SPSS 21 statistical package [26]. All exam results were evaluated on a scale of quantitative characteristics (interval scale), and the Kolmogorov-Smirnov and Shapiro-Wilks tests confirmed the presence of a normal distribution of individual results in the samples. Thus, the presence of an interval scale and a normal distribution allowed the use of standard parametric statistics:

1. Arithmetic means, standard deviations and errors of the mean result were calculated to evaluate the samples.
2. For a more confident understanding of the presence or absence of a certain trend in average examination scores (English and analytical chemistry) with years of study, the experimental curves of average scores in the groups were approximated by first- and second-order curves. In the future, only approximation curves with maximum coefficients of determination (R^2) were used for analysis, i.e. curves with the maximum proportion of the variance of the dependent variable explained by the applied model. It turned out that for all cases, linear approximation demonstrates the best results (maximum R^2).
3. To assess the significance of the difference between samples of different years of entry, either the t -test (for an independent pair of samples) or the one-way ANOVA statistic (for several pairs of samples) was used. When comparing several samples, their homogeneity was first examined using Levene's test of homogeneity of variance. Then, multiple posterior comparisons were applied to determine which pairs of samples demonstrate a significant difference.
4. The statistical relationship between variables was assessed through paired Pearson linear correlation coefficients.

3. Results and discussion

3.1. *Learning analytical chemistry*

When teaching using a foreign language, the most logical thing seems to be the presence of a direct correlation between the levels of language proficiency and the discipline being studied. Such dependencies have been repeatedly observed in the literature [27–29]. At the beginning of the research in 2019, a very strong Pearson correlation ($r = 0.89$) was also found between the results of a special test on English chemical terms and an exam in analytical chemistry [19]. It should be noted that the language test conducted was only a means of assessing the students' minimal readiness to listen to lectures in English and did not contain an overall assessment of language knowledge. Nevertheless, the impact of elementary English knowledge on the chemistry study turned out to be very significant.

Further, more in-depth research over several years has shown that the correlation between language and analytical chemistry knowledge is very weak, if it exists at all, for students of both disciplines. It is insufficient for predicting progress in studying scientific disciplines related to language knowledge. The English language proficiency level of students of both specialties

steadily and monotonically increased with the years of enrollment (figure 1a). The average examination scores of the initial 2019 year of enrollment increased by 14-15 points in both groups by 2023. This difference is statistically significant at the $p < 0.001$ level. As shown in figure 1a, the experimentally determined dependence of the average score obeys a linear approximation with high values of the coefficient of determination $R^2 > 0.972$.

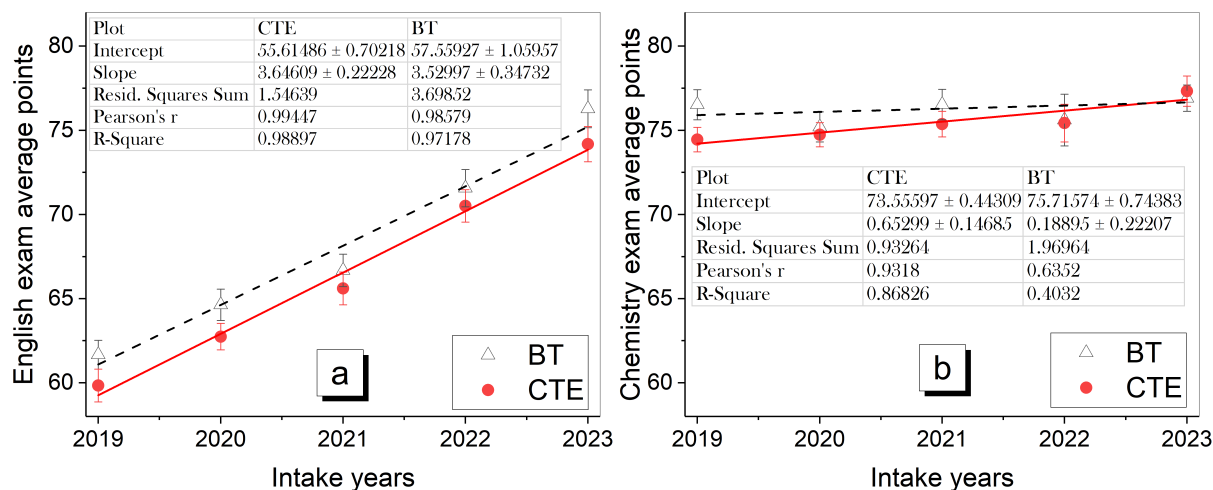


Figure 1. Average exam scores in English in the first year of study (a) and analytical chemistry (b) for students of the specialities of BT and CTE of the 2019-2023 intake years. The parameters of linear approximation are given for each experimental plot.

Against this background, the knowledge of analytical chemistry did not reveal cases of a statistically significant difference at the $p < 0.05$ level as a function of the years of enrollment. In other words, the average examination scores remained static over the years. However, a particular trend occurred towards increasing scores (figure 1b). This trend is especially noticeable for the CTE speciality. Applying linear approximation for CTE gives a high coefficient of determination $R^2 = 0.868$. For the BT speciality, $R^2 = 0.403$, i.e., one can speak of a linear trend quite conditionally.

Lecturers, program content, target competencies and training terms were unchanged throughout the observation period. Over the years, the growing popularity of English-language educational programs intensified competition among applicants, improving understanding of the importance and attention to language training. Under such conditions, an increasing level of English proficiency is expected.

Figure 1a shows that in the first year of intake, the average examination score fluctuated around 60 points, that is, on the border between a negative and a positive exam result. In the last studied year of intake, the level of examination marks reached 75 points (an increase of approximately 15 points), which corresponds to the typical average level of examination marks in universities on a 100-point scale. It can be assumed that in the future, the increase in English marks will slow down or stop altogether.

The lack of mobility of the examination results in analytical chemistry did not seem obvious and required additional explanations. It should be noted that, for the first intake, students received an average of 74-76 points. In other words, the level of knowledge in chemistry turned out to be significantly higher than in English (the difference is at the level of 15 points). Further progress in chemistry is more problematic. Indeed, for the last year of enrollment, the exam scores were approximately 77 points, i.e. the improvement was only 1-3 points over 5 years of enrollment. That is, the rather high level of exam scores in analytical chemistry of the first year

complicates the prospects for their further growth. On the other hand, there are no guarantees that the growth trend will be maintained.

The training took place during the spread of the COVID-19 epidemic, which significantly affected the educational process [30]. As was already mentioned, only training in 2019/20 and 2023/24 was implemented in the classical version with students and lecturers in classrooms. During 2020/21 and 2021/22, strict restrictive measures were in force in China. Students were at home, and teachers were in Ukraine. Lectures and even practical classes were held exclusively remotely. Quarantine was partially eased in the 2022/23 academic year when students were allowed into the classroom with Chinese tutors. However, Ukrainian lecturers remained in distance learning conditions.

The abrupt and unexpected transition from offline to online learning had at least two negative consequences. First, the lecture structure, optimised for offline learning, proved to be far from optimal for online learning conditions. The second aspect is a significant weakening of the connection between the lecturer and students. Being in the classroom, the lecturer had every opportunity to observe the reaction of students during the learning process. He could react accordingly, varying the pace of teaching, making additional emphasis, repetitions, clarifications at specific points, or omitting unimportant details if necessary.

Analytical chemistry is usually classified as more applied, rather than purely theoretical. Manual skills and abilities occupy a larger space in analytics. Practical laboratory work suffered most during the COVID period. Constant face-to-face contact with the lecturer, the ability to clearly demonstrate and simultaneously explain specific experimentation techniques, are important primarily for applied sciences. In the conditions of COVID, students were deprived of educational exercises and training. A characteristic indicator is a significant decrease in students' activity in communicating with lecturers during online learning. Among the obvious reasons are speech restrictions, not always ideal Internet connection, as well as the impossibility of free communication during out-of-class time. There are reasons to believe that, unless the identified negative factors are overcome, learning outcomes could gradually deteriorate.

The changed learning conditions and some observations from the first year of work triggered the updating of the instructional design. The negative background brought to the forefront the task of preventing a drop in the level of material assimilation. Analysing possible changes, the authors concluded that they are all united by an attempt to optimise the cognitive load of students studying under conditions of a non-native language. The updating of educational materials and their adaptation to the needs of students were based on the provisions of the theory of cognitive load [31–33] and taking into account the conditions necessary for the formation of stable connections between chemical knowledge at different levels of its representation [34, 35]. These generally accepted theories made it possible to determine the main directions for revising educational materials.

To date, discussions on understanding what constructs cognitive load consist of, how best to interpret the results of measuring cognitive load, and how to formulate hypotheses that include the relationships between individual components, the overall load and learning outcomes are ongoing. The theory of cognitive load was partially revised after 2010, so in the literature, one can find so-called old and new CLT variants [36]. Cognitive load is often characterised as the amount of “mental energy” required to process data. It is referred to as “working memory”, which provides a place for temporary storage of data, learning, and reasoning [31]. The existence of two types of cognitive load – intrinsic and external – and the additive nature of the total load is unanimously recognised by theorists [36]. Accordingly, the review addressed each of these types.

Intrinsic load is primarily determined by the complexity of the material and the student's prior knowledge. External cognitive load can be extraneous and germane. Extraneous load is caused by external conditions regarding the material's content and students. For example, it can

be caused by poorly developed instructions, unsuccessful design, or a combination of educational materials in such a way that the channels of perception are overloaded, etc.

Germane load goes beyond simply overcoming internal load. It is needed to construct schemes and carry out learning. This load is beneficial because it directly contributes to learning; it is often associated with learning motivation. If intrinsic and/or extraneous load is too high, there is no “room” for germane load, and learning will not occur. Some scholars emphasise that germane load is not just any useful load. It arises from those additional, labour-intensive aspects of learning that go beyond task performance, such as conscious reflection and self-explanation [36].

Each type of load must be managed appropriately (reduced or increased depending on the magnitude of the total cognitive load and available working memory resources). Effective instructional design should keep the total load below the limits of working memory, allowing for effective learning [37]. Where the intrinsic load is quite high due to complex content and low prior knowledge, the extraneous load should be reduced. On the other hand, where cognitive overload is not a concern, there is no need to mitigate extraneous load. In some cases, increasing the load is reasonable, e.g., introducing interesting but potentially distracting details for motivational purposes.

3.2. Updating the instructional design to optimise intrinsic cognitive load

Optimising internal cognitive load is a key factor in facilitating learning. The complexity of the content of the material determines intrinsic load. However, it cannot be determined simply from the analysis of the educational material and must be established only with the specific level of knowledge of the learner.

Intrinsic cognitive load is influenced by the material’s complexity and the learner’s prior knowledge level. The dependence on the complexity of the educational material is determined by the number of elements that need to be integrated into the content structure, simultaneously processed and held in working memory. According to CLT, an “element” is everything processed by short-term memory as a whole unit. An element can be either a unit of new information or an already-formed learned scheme. The load on short-term memory in the learning process depends on the number of elements that must be processed simultaneously and on the degree of interactivity of their interaction [37]. The interactivity of the interaction of elements also depends on the learner’s prior knowledge.

It was decided to make changes taking into account the principles of segmentation and prior learning, as well as the effect of modalities, to reduce the internal cognitive load of students. Methods were used that ensure gradual processing of the material, the first of which is the transition from simple to complex, as well as the “part-whole” approach, where before the integrated task is presented, the student first gets acquainted with individual elements of the material [38]. This approach turned out to be the most promising, as evidenced by the results of our analysis. At the beginning of studying the discipline, using many symbolic records was avoided, replacing them, where possible, with illustrations. The number of symbolic records on the slides gradually increased following the growth of students’ knowledge.

The total number of slides for the discipline was reduced by 16% (figure 2a). As is known [17, 18], learning a foreign language creates an additional cognitive load since it requires extra effort to translate/understand words and terms in both directions mentally. Accordingly, optimising the number of slides helps eliminate the overload problem.

At the same time, reducing the number of slides was not an end; it aimed to solve several tasks. First, situations are removed when the same information is presented in several autonomous formats. Thus, the so-called redundancy effect is significantly reduced [36]. In addition, reducing the total number of slides helps to reduce text fragments. At the same time, a larger number of educational pieces appear, which, in terms of their focus and teaching logic, are closely related and located next to each other. It allows you to structure information to display connections

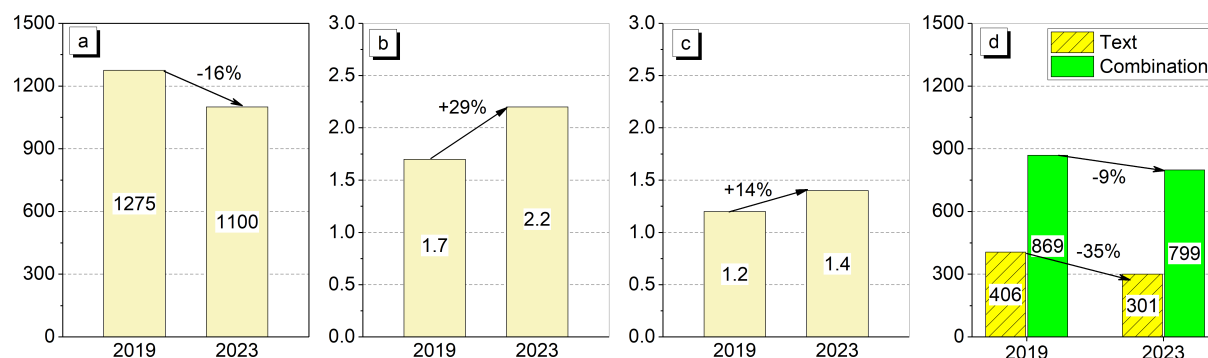


Figure 2. Changes in lecture presentations in 2023 compared to 2019 to optimise internal load: reduction in the total number of slides (a), increase in the average number of elements on slides of all types (b) and slides with illustrations (c), accelerated reduction in the number of purely text slides compared to combined ones (d).

between related fragments within the same screen. As a result, the number of integrated slides in presentations has increased.

It is illustrated by the change in the average number of elements on slides of all types (figure 2b) and slides with illustrations (figure 2c). This approach made the presentation of the material more logically coherent and made it possible to present it at appropriate intervals. It gave students enough time to process important information through visual and auditory channels and complete cognitive processing, particularly to understand individual elements and their connections.

According to CLT, interconnected elements are combined into a scheme, which is then perceived by short-term memory as a single element [37]. In addition, this reduces the effect of splitting attention. When fragments of related information are presented in an integrated format, the student's working memory is not burdened with the need to link it [36]. It helps to reduce the load on short-term memory. Given that the training took place in a foreign language, the number of elements for simultaneous study was limited to 5, in contrast to the well-known 7 ± 2 elements that short-term memory can retain for 20 s [39]. As a result of those mentioned above, the reduction in the number of purely text slides was faster than combined slides of different types (figure 2d).

Since 2020, a slide lecture summary manual has been introduced into the training. A key element of this manual is the requirement for students to self-prepare for each subsequent lecture. Pre-translation and mastery of new chemical vocabulary help students listen to lectures and read the manual with improved comprehension. A conscious attitude towards preparing for lectures causes the so-called "self-explanation effect", which encourages students to generate explanations (to themselves) for how they think about the concepts being studied and what they do to master the topics. Previewing the material before the lecture gives an idea of what will be covered and prepares the brain for learning the details. This approach promotes the development of anticipatory thinking, thanks to which students are more actively involved in the lecture and better remember the information.

3.3. Updating the instructional design to optimise extraneous and germane cognitive loads

One postulate of cognitive load theory is the need to reduce extraneous load and increase the germane load to maximise the use of cognitive resources and facilitate learning [37].

An extraneous load is considered to be a load that is not necessary and is not directly

related to the construction of knowledge schemas. Extraneous cognitive load results from poorly designed instructional materials. The teaching techniques, procedures, and materials used during learning impose it. Instructional design is effective when extraneous load is minimised, as this frees up working memory resources for processing the primary material. The conditions of studying chemistry in a foreign language impose additional constraints. The combination of high intrinsic and extraneous cognitive load can become critical for learning, as it can significantly exceed the capabilities of working memory.

We tried to create conditions under which the volume of working memory was not exceeded, and the load remained manageable. Three approaches were used to analyse the existing lecture materials and modernise them.

First, the number of slides with optimised spatial and temporal structures was increased. Situations where students needed to recall information from the previous slide for understanding were eliminated. On the contrary, a two-stream presentation of data was much more often used. The first stream stores the information necessary for understanding, which is always on the screen. The second stream is devoted to the next studied details, which are strongly related to the information of the first stream (figure 3a and figure 3b). Thus, the “split attention effect” is prevented. It is known that students learn better from one integrated source of information than from several sources of information distributed either in space (spatial splitting) or in time (temporal splitting of attention) [33]. Learning from distributed sources of information requires more attention switching and, therefore, complicates the process of mental integration necessary for understanding the educational task compared to learning from integrated sources. Learning from integrated sources of information imposes less extraneous load.

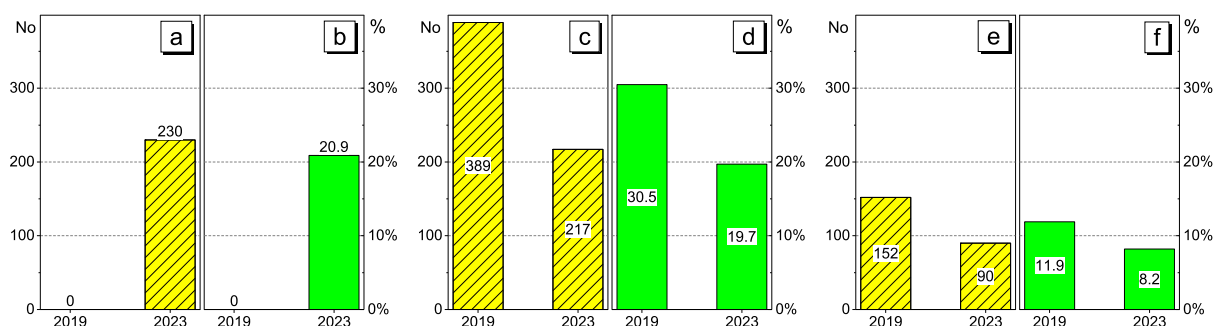


Figure 3. Optimisation of extraneous cognitive load in lectures in 2023 compared to 2019 by increasing the number (a) and proportion (b) of slides with two-stream data, decreasing the number (c) and proportion (d) of slides with dominant text, decreasing the number (e) and proportion (f) of slides with dominant illustrations.

The second direction is to reduce the number of slides containing only text (figure 3c and figure 3d) or only illustrations (figure 3e and figure 3f), i.e., to adhere to the multimedia principle. It was observed that more experienced students could achieve the best results by studying only illustrations of diagrams, while beginners needed illustrations and additional written information. As far as possible, attempts were made to involve the visual-spatial and auditory modalities of the listeners (two channels of perception), not only the visual-spatial modality. Usually, the modality effect is well-studied in CLT. It can be partly explained by the increase in the total volume of working memory when two working memory subprocessors are used in parallel instead of one [33].

The third direction is to increase the number of working examples of solving problems (figure 4a and figure 4b). Beginner students learn more efficiently by studying examples that give

them solutions. Students use most of their resources when solving a new problem by applying a problem-solving strategy. Such an approach imposes a very high extraneous cognitive load and leaves no resources for learning. When solving problems with complex data and/or multiple steps, reasoning strategies that do not rely on algorithms almost always fail [38]. Trying to reason without an algorithm quickly overloads cognitive resources.

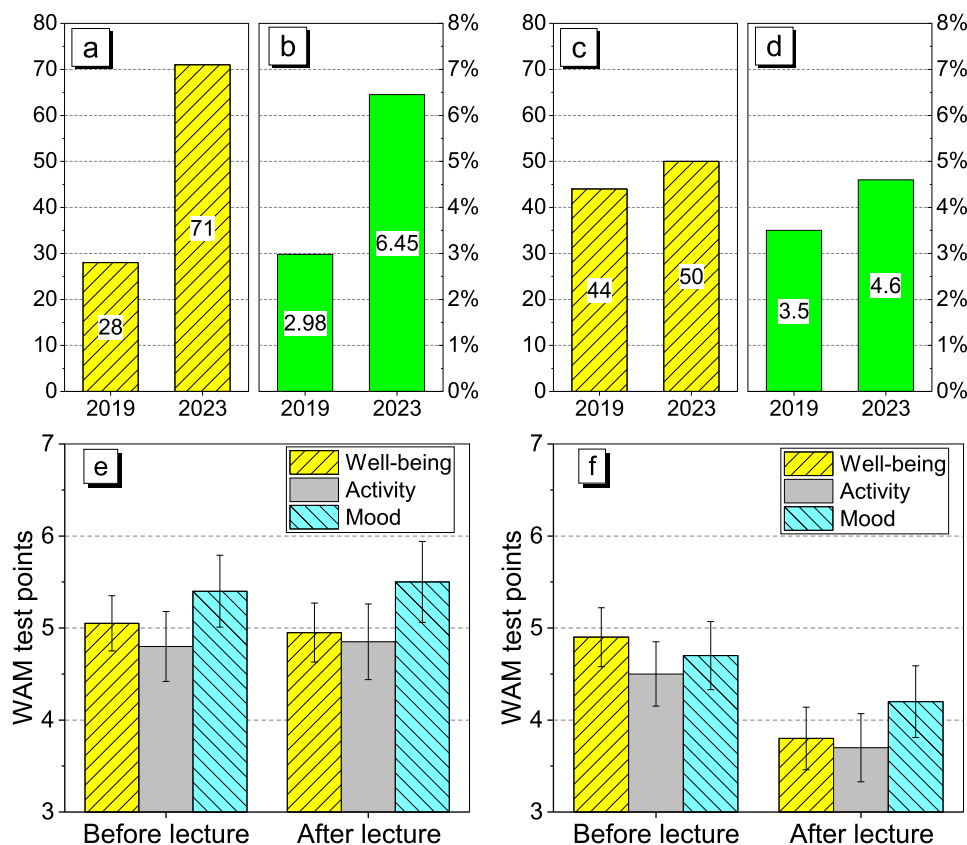


Figure 4. Comparison of lectures in 2023 relative to 2019 in terms of optimising the relevant cognitive load: a, b – increase in the number and share of problems, c, d – increase in the number and share of slides with diagrams to demonstrate the connections between concepts and reflect the situation as a whole. The change in WAM test scores before and after lectures conducted with (e) and without (f) considering the profiles of learning preferences of groups.

There are many algorithms for each type of task. However, memorising the different steps can create obstacles if several algorithms are used simultaneously. For this reason, it was decided to identify and teach one “best” algorithm for each type of task. The most valuable algorithms were chosen according to the following criteria: broad applicability, based on fundamental concepts, and ease of memorisation. At the same time, it is difficult to determine which type of cognitive load was adjusted in this way. Reducing the number of options for memorisation reduces probably intrinsic cognitive load.

In contrast, algorithmising the construction of new knowledge schemes, creating a sense of ease of assimilation, is more related to the germane load and contributes to learning motivation. The germane cognitive load determines the effort required for processing, internal organisation, integration, and construction of cognitive schemes. It depends on the available working memory capacities and is an aspect of the learner’s self-regulation associated with motivation and interest.

Increasing germane cognitive load can significantly affect task performance and is associated with higher levels of expertise and productivity.

In revising lecture materials to increase the germane cognitive load, slides containing diagrams for organising information, demonstrating the relationships between concept elements, and presenting problems as a whole have been expanded (figure 4c and figure 4d). The number of slides that provide a bridge between unfamiliar concepts and the knowledge that students already possess has increased. The construction of diagrams contributes to the feedback effect: students with prior knowledge can view complex information as a single fragment, which reduces the interaction of elements [37]. From this point of view, the importance of the student-organised knowledge base in long-term memory is determined primarily by its ability to reduce effectively the capacity limitations of working memory. This reduction occurs by encapsulating many information elements into higher-level fragments that can be considered single working memory units.

The combination of reducing extraneous and, at the same time, increasing germane cognitive load ensured the redirection of students' attention from processes not related to learning and directing it to the processes associated with learning, in particular, towards the construction and awareness of knowledge schemes.

Hanham et al. [33] argue that pleasure is a motivator and a factor for increasing cognitive resources. It means that pleasure should be promoted as an emotion that supports learning. In contrast, their results show that disappointment is a demotivator, reducing students' resources. These findings are consistent with a study of students' perception of lectures with multimedia presentations. Subjective functional states (well-being, activity and mood or WAM) were assessed on a 7-point Likert scale with negative and positive poles according to the results of a test of 30 questions (from three subscales – 10 points for each state) [40]. The average value was calculated for each subscale. The value of the average score on the scale above 4 meant an optimal psychological state, and the value below – vice versa.

The conducted testing according to the WAM method revealed that the subjective functional states of students improve under the conditions of using multimedia presentations in lectures, which was developed by taking into account individual and group differences in learning preferences. Such an improvement leads to a certain increase in the WAM test scores and the convergence of individual indicators (figure 4e). Conversely, WAM indicators decrease after listening to lectures prepared without considering the students' learning preferences (figure 4f).

3.4. Three levels of chemical knowledge representation and interlevel links

Conceptual structures of chemical knowledge are formed through the relationships between different concepts that reflect the understanding of chemical properties and interactions. It includes the study of theories, laws, models and fundamental concepts that determine the scientific understanding of chemistry. Mastering chemical knowledge occurs at three levels: the microlevel (the structure of atoms and molecules), the macrolevel (processes at the level of the material world) and the symbolic level (description using mathematical models). Knowledge must be mastered at all these levels, with the possibility of transitioning between them, to form clear conceptual structures. Since none of the three levels is higher than the other but complements each other, ensuring that students understand the role of each level and the correlation of one level with another is an essential aspect of creating understandable explanations. The identified shortcomings in constructing primary educational materials were related to insufficient attention to solving this task. Eliminating such shortcomings was the next step in optimising instructional design.

The presentations were improved in terms of elements that included different levels of representation, emphasising their interconnection. The first lecture explained to students the need for a multi-level understanding of the phenomena being studied. As a basis, a scheme

built on the ideas of the Johnstone triangle [41, 42] was used. Two cases were considered that correspond (figure 5a) or do not correspond (figure 5b) to the conditions necessary for mastering chemical information and further forming conceptual structures of knowledge. The scheme consists of three circles in both cases, labelled macro, micro and symbolic.

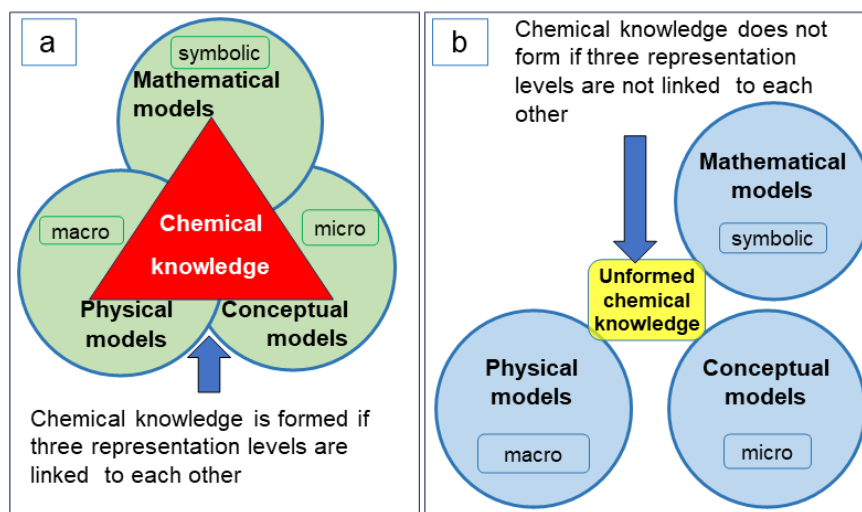


Figure 5. Schematic representation using Johnstone's triangle of the conditions necessary for the formation of chemical information (a) and the lack of formation of chemical knowledge (b).

Figure 5a illustrates that rather than focusing on one level of representation or one connection between the circles, successful chemistry teaching is predominantly conducted internally, at the intersection of the circles. Accordingly, students must cope with all three levels of knowledge acquisition simultaneously. The array of formed chemical knowledge is conventionally indicated by a triangle, which contains knowledge at different levels as its integral components.

Figure 5b, on the contrary, focuses attention on the possible disjointedness of the three levels of knowledge. Such a situation makes it impossible to transition between levels. Even if chemical information is mastered at one level, it is difficult for the student to extend and use the acquired knowledge at another level. Under such conditions, the mastered chemical information is fragmentary. It, in turn, complicates the formation of conceptual structures of chemical knowledge. When optimising presentations for each topic, several fundamental points were observed.

1. We began teaching the material from the macroscopic level. It is most convenient for beginners to work with concepts they can observe or measure directly. We focused on phenomena and processes already familiar to students in practice [38].
2. We gradually introduced the microscopic and symbolic levels. First, we considered double transitions, and after understanding them, we moved on to clarifying triplet bonds.
3. To demonstrate the transition between levels, we used various methods of presenting the material (graphs, models, demonstrations, chemical equations, etc.).

The optimisation results are presented in figure 6. They consist of the number of slides illustrating concepts at individual levels of knowledge, which has decreased (figure 6a – figure 6c).

It should be noted that the number of slides with illustrations for one level of knowledge decreased by approximately the same amount (45-60 slides for each level – figure 4c) but did not disappear completely. According to the authors, such simplified slides are still important when teaching specific topics.

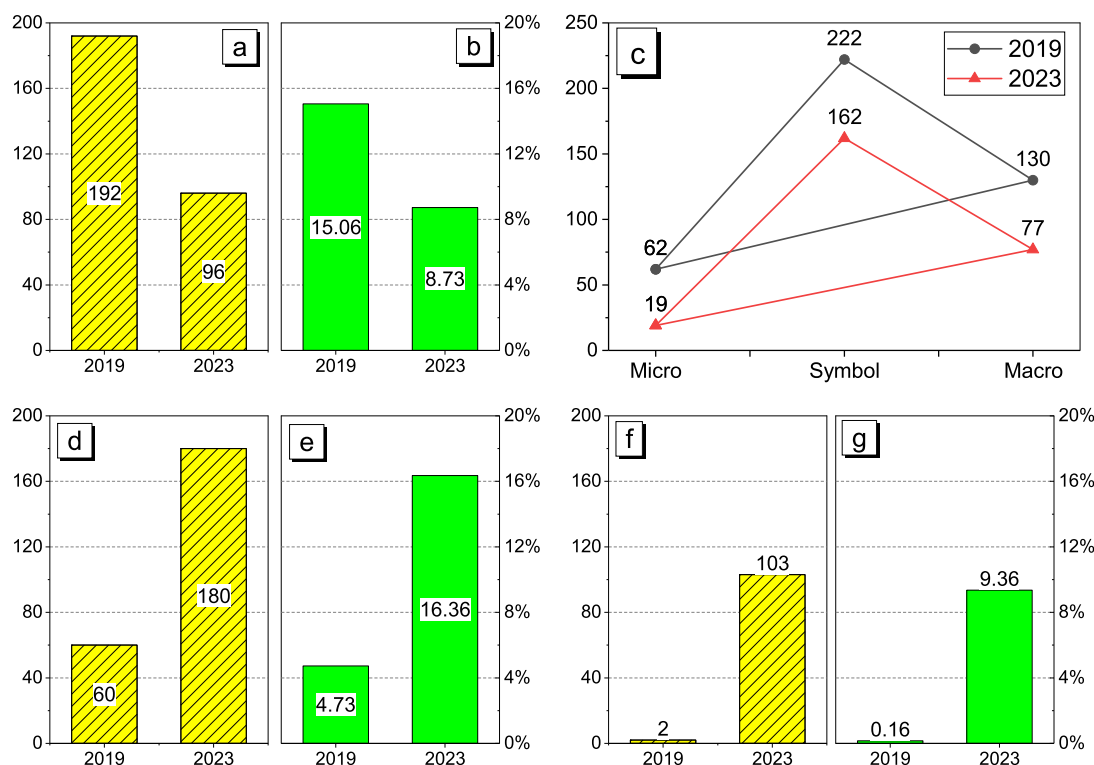


Figure 6. Presentation of chemical knowledge at different levels in lectures in 2019 and 2023: a, b – separate levels of knowledge (number of slides and their proportion), c – number of slides with information at each of three separate levels, double (d, e) and triple (e, g) transitions between levels (number of slides and their proportion).

At the same time, the number of slides illustrating at two (figure 6d and figure 6e) and three levels (figure 6f and figure 6g) with transitions between them increased. The most complex triple transitions demonstrate the most significant growth. They were practically absent in the initial lectures but increased to almost 10% of the total number of slides after optimisation.

According to the authors, the approach used corresponds to the postulates of the cognitive load theory discussed above. It is a tool that promotes the gradual mastery of complex chemical concepts. Using the “triangle” of triplet bonds helps reduce information overload, which often occurs in beginners due to the need to simultaneously process information at the macroscopic, microscopic and symbolic levels. Structured presentation of the material, particularly through graphic tools, allows students to assimilate the content more efficiently, reducing the pressure on working memory and becoming a meaningful basis for generalising concepts. This approach also stimulates teachers to coordinate the language and symbols they use when teaching chemistry better, which becomes critical in conditions of teaching in a non-native language.

4. Conclusions

The level of English language proficiency of KCQUT students, according to the results of the exam at the end of the first year, gradually increased over the years of enrollment – from 60-62 points on average in 2019 to 74-76 points in 2023. This trend is a consequence of the improvement of the language abilities of applicants in the context of the popularisation of the project and increased competition for admission. At the same time as the improvement of English results, the examination results in analytical chemistry practically do not improve over the years, remaining

without statistically significant changes within 75-77 points.

An analysis of educational results over 5 years showed that changes in the educational environment during COVID-19 (2020-2022), primarily the forced transition from traditional to predominantly distance learning, outlined several shortcomings in the educational materials used. Their presence was among the identified reasons for slowing down the improvement of chemistry knowledge when comparing students of different years of enrollment. It prompted a gradual optimisation of teaching materials throughout the years of observation following the theory of cognitive load and for acquiring chemical knowledge at different levels.

Recommendations are formulated to optimise presentations for teaching analytical chemistry in a foreign language. In general, they can potentially be used in teaching other chemical disciplines. It is recommended:

- a) Ensure gradual processing and complication of the material – use the “from simple to complex” method, the “part-whole” approach, and increase the number of symbolic entries gradually, following the level of students’ knowledge.
- b) Optimise the total number of slides and present information concisely. Adhere to the principle of multimedia. Try to use the visual-spatial and auditory modalities of the listeners (two channels of perception).
- c) Prevent the effect of redundancy – avoid presenting data in several autonomous formats simultaneously and limit the number of new elements for simultaneous study.
- d) Avoid the effect of splitting attention and situations when students need to use data presented in a disjointed manner in time or space for understanding. Present related data in two streams or leave the necessary on the screen to demonstrate connections if possible.
- e) Organise preliminary training. For example, introduce a synopsis that reproduces the materials of the slides and provides a place for translating unfamiliar words, provide clear instructions for preparing students for each lecture and require their implementation.
- f) Use algorithmisation to demonstrate examples of solving problems. For each type of problem, choose the “best” algorithm that is simple, based on basic concepts and has a wide range of applications. Avoid using multiple algorithms at the same time.
- g) Use graphic diagrams to organise information, demonstrate connections between concepts and build “bridges” between new and existing knowledge. Diagrams simplify perception, reducing cognitive load by grouping complex data into higher-level fragments, which are then held in working memory as a whole.
- h) Explain the importance of simultaneously understanding the macro-, micro- and symbolic levels of chemical knowledge in the first lecture. Teaching should focus on the intersection of these levels to form a holistic perception of the material.
- i) It is better to start explaining from the macroscopic level, focusing on phenomena and processes that students can directly observe or measure and those they are already familiar with in practice. After mastering the macroscopic level, it is worth gradually introducing the microscopic and symbolic levels, starting with explaining double transitions and moving on to triplet bonds after mastering them.
- j) Use various methods of presenting the material (graphs, models, demonstrations, equations, etc.) to make the transitions between different levels clearer and improve understanding.

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Organisation of students' reflective activity when studying the topic "Oxygen-containing organic compounds"

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Abstract. This study is devoted to exploring the possibilities of using reflective activities when studying the topic "Oxygen-containing organic compounds" in the school chemistry curriculum. The experience of domestic teachers in the application of reflective activities in chemistry lessons is analysed. Methodical recommendations for conducting lessons using different types of reflection in grades 8 and 9 have been developed. The results of a survey of teachers showed limited use of reflective activities, which are reduced to reflection on the emotional state and comprehension of students' activities through questioning. Based on the analysis of scientific literature and teachers' practical experience, lesson plans, instruction cards for laboratory and practical work with elements of students' reflective activity have been developed that can be used in the practice of chemistry teachers. The developed materials are aimed at increasing students' interest in the subject, encouraging the search for information, deepening students' knowledge, and applying information and communication technologies in teaching.

1. Introduction

In the context of reforming and modernising the educational environment, the issue of socialisation of student youth, development of their readiness for innovative activity, quick comprehension of information, mobility, self-awareness of motives and principles of their own activity is actualised. At the same time, within the context of European integration processes in education and the implementation of the principles and ideas of the New Ukrainian School, there is an increasing need for new educators who are not only capable of clearly formulating and effectively solving specific didactic tasks in teaching (transmitting educational information, organizing the process of its qualitative assimilation, assessing the level of students' knowledge and skills, etc.), but also act as active agents of professional activity based on the principles of pedagogical partnership, learner-centered, and competency-based approaches. In this context, reflective activity plays an important role, aimed at ensuring self-design and creative development of both the teacher's and the students' personalities [1].

From the perspective of pedagogical practice, reflection constitutes an intellectual and emotional activity through which a teacher analyzes his or her teaching experience to achieve high-quality learning outcomes for a student [2]. To acquire the competencies necessary for



successful social integration, personal growth, and professional activity in adulthood, a student must already in school learn to independently obtain information, formulate and, through discussion, defend his or her own position, and collaboratively solve specific problems. Reflection serves as a system-forming factor in organizing thinking, activity, and communication.

Today, high-quality chemistry teaching cannot be realized without the use of tools and opportunities provided by reflection, especially when introducing students to complex chemical material that includes a large number of terms and chemical reaction equations. The application of various types of reflection (emotional, related to the content of educational material, and related to activity) in chemistry instruction enables the teacher to: compare actual educational outcomes with the predicted ones, identify key topics for discussion with students, develop their motivational sphere, cognitive activity, and mobility, and to adjust what has been learned by students. It also enables students to: reconsider their own experience of studying chemistry, deepen their theoretical knowledge, improve their skills, develop intellectual capacity, independence, and creativity, and enhance their level of self-development and self-education.

The topic “Oxygen-containing organic compounds” is one of the most important in the school chemistry course. At the same time, in modern school practice, there is a weakening of students’ attention to the study of organic compounds, due to the complexity of mastering the educational material. Students acquire chemical knowledge and skills in different ways. They often doubt their own abilities due to the difficulties involved in studying chemistry. Systematic diagnostics and constant monitoring of students’ competencies, adjusting the learning process through reflection, and creating a trajectory for the development of students’ reflective processes will help overcome educational losses and improve the study of the subject “Chemistry” in secondary school.

A theoretical analysis of literary sources and the practical experience of teachers also shows that the possibilities of reflective activity in the study of rather complex educational material in chemistry by students are realised only partially. In this context, the work is relevant and aimed at organising the reflective activity of students in the study of the topic “Oxygen-containing organic compounds”.

The *purpose* of the work is to substantiate methodological approaches to organising students’ reflective activity when studying the topic “Oxygen-containing organic compounds”.

According to the purpose, the following tasks of the work are defined:

- 1) to determine the structure, types, and features of organizing reflection in the educational process;
- 2) to examine the current state of organizing students’ reflective activities in the practice of school chemistry education;
- 3) to develop lesson fragments incorporating elements of reflection for the topic “Oxygen-Containing Organic Compounds” and to justify the feasibility and significance of implementing reflective activities in chemistry instruction.

2. Literature review and theoretical framework

In modern scientific literature, there are many approaches to understanding the essence of the phenomenon of reflection (Latin *reflexio* – “turning back”): “introspection”, “self-assessment”; “assessment of the prerequisites, conditions and results of one’s own activity”; “reflection on one’s internal state”; “introspection of activity and its results”, etc.

From the point of view of pedagogical practice, reflection is an intellectual and emotional activity, in the process of which the teacher comprehends his pedagogical experience in order to obtain high-quality results of student learning [2].

Several studies have explored the experiences, perceptions and reflections of students and instructors regarding the shift to remote learning in chemistry education during the COVID-19

pandemic. Bahrami et al. [3] conducted semi-structured interviews with introductory chemistry students at two US universities. Among the topics covered were the difficulties that arose, the adaptations made, and recommendations for improving the forms, methods, and technologies of distance learning. Despite the difficulties, the students demonstrated resilience in developing new learning strategies, cognitive activity, and interest in interactive reflection. The instructors reflected on student feedback to design custom pedagogical approaches for their remote courses. Similarly, Sunoqrot et al. [4] shared the views of chemistry teachers at the Faculty of Pharmacy in Jordan during the rapid transition to distance learning without adequate technological support. They emphasize the efforts to ensure continuity of learning and achievement of educational outcomes under challenging circumstances (changes in learning material, teaching methods; reflective activities of students and teachers).

Specific chemistry subdisciplines have also been examined. Tran et al. [5] compared the experiences of organic and analytical chemistry lab instructors, identifying common challenges in the online format, such as experimental implementation, assessment, technology disparities, and synchronization of student attendance. Proposed solutions included creating edited video content, offering flexible scheduling, and planning for future interactive or hybrid lab formats, increasing motivation to study chemistry, organizing reflection in the educational process.

At the secondary school level, An et al. [6] investigated chemistry teachers' reflections on using online platforms during the pandemic in Malaysia. Findings indicated that student-centred strategies like project-based and game-based learning could be effectively implemented online. The crisis provided opportunities for teachers to innovate with educational technologies to improve student engagement and enthusiasm, reflective activities in chemistry instruction.

Beyond the pandemic context, various reflective accounts have discussed other aspects of chemistry education. Erduran and Kaya [7] presented teacher educators' reflections on incorporating the philosophy of chemistry themes into pre-service teacher training. The self-study explored their own learning journeys and professional identity negotiations at the intersection of chemistry education, philosophy and teacher preparation. In the realm of environmental education, De Abreu et al. [8] analyzed how secondary school teachers' perceptions of the environment shaped their teaching practices and students' views on environmental preservation, reflecting on implications for chemistry teacher preparation at the university level.

These diverse reflective studies, situated in different educational contexts and time periods, provide valuable insights into the experiences, challenges and opportunities involved in chemistry teaching and learning. They highlight the importance of gathering and acting upon student and instructor reflections to enhance pedagogical approaches, technological integration, and teacher professional development in the field of chemistry education. The reflective activity of students in chemistry lessons is a complex, integrative phenomenon based on the reflective skills of students as a result of awareness of themselves as subjects of educational activity.

The reflective activity of students has a five-component structure (personal, intellectual, communicative, cooperative and regulatory components), capable of positively influencing the effectiveness of the activity of all participants in the educational process [9].

Figure 1 presents the main stages of students' reflective activity while studying chemistry. Let's explore each stage in more detail.

Stage I – "Transpositional stage" of students' reflective activity consists of the student's change of role position, which is reflected in the transition from the position of the subject directly carrying out educational activities (acquiring knowledge) to the position of the subject analysing it. It is assumed that the student will be able to take an external position in relation to his actions.

Stage II – "Reproductive stage" – involves students reproducing the entire sequence and methods of educational activity during the study of the topic in the chemistry lesson, recalling the emotional reactions of themselves and classmates, as well as their own feelings and experiences

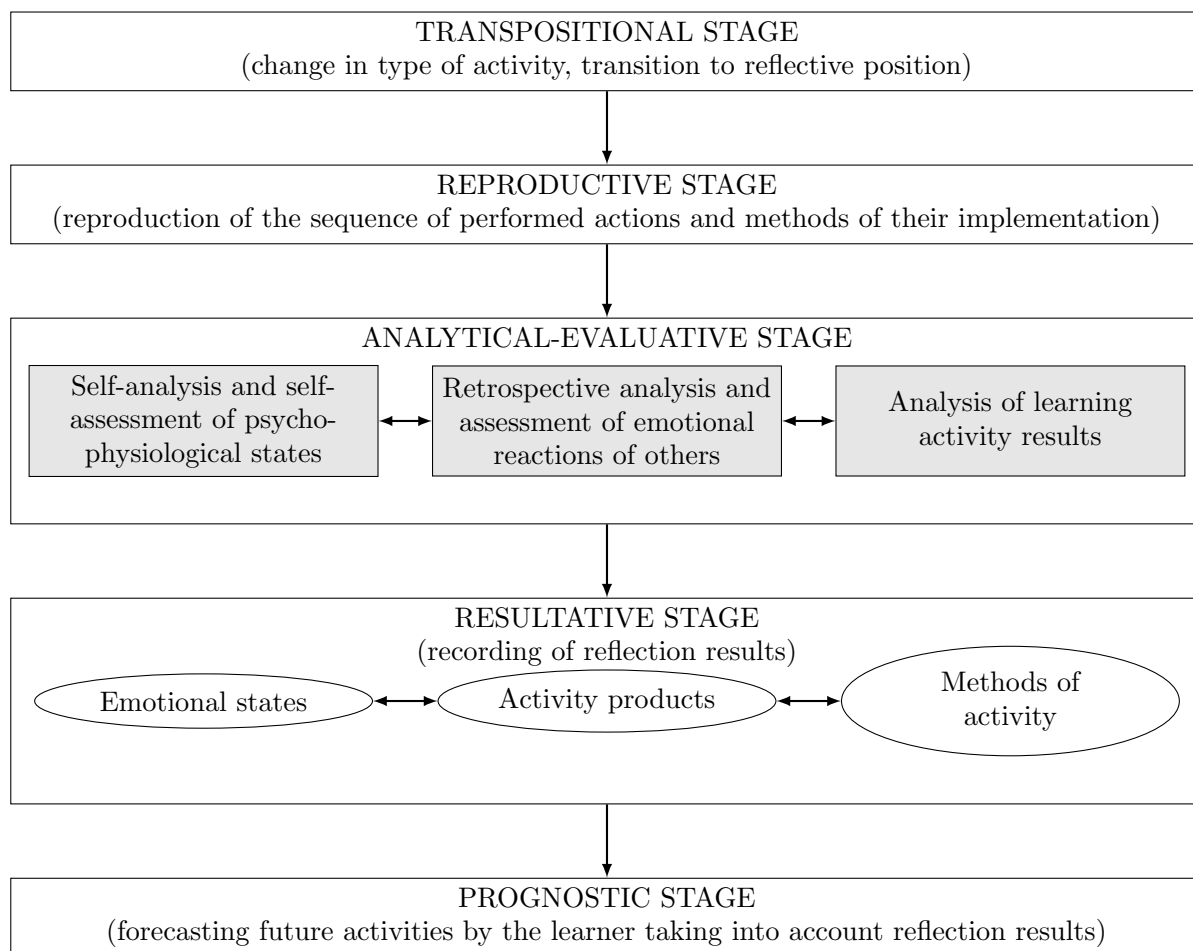


Figure 1. Stages of students' reflective activity in chemistry lessons.

in the process of educational activity.

Stage III – “Analytical-evaluative stage” – consists of students carrying out a multifaceted analysis of all components of the educational activity performed in chemistry lessons, evaluating its effectiveness, and identifying a set of factors that influenced the success/failure of acquiring new knowledge and skills.

Stage IV – the “Resultative stage” – is associated with formulating reflection results, which, in turn, involves the student's fixation on the obtained educational product (new knowledge, creative ideas, etc.), the methods of educational activity used (traditional, interactive, combined, innovative), and the emotional states of the educational activity subjects.

Stage V – “Prognostic stage”, or “Final stage” – students' activity in chemistry lessons is aimed at obtaining advanced information about the prospects for the development of further study of the subject (chemistry), assimilation of the acquired knowledge and its practical application in life.

Analysis of modern psychological-pedagogical and methodological literature on the research problem made it possible to distinguish a number of classifications of reflection that can be used in chemistry lessons. In particular, by content, reflective activity in chemistry lessons is divided into:

- 1) *symbolic reflection*, the essence of which is the student's self-assessment using symbols (cards, tokens, gestures, etc.);

- 2) *oral reflection* consists in the ability of students to express their thoughts, and describe their own emotional states coherently;
- 3) *written reflection* is used at the final stage of studying a certain topic in chemistry and involves the use of various techniques.

By form of activity reflection is divided into:

- 1) individual reflection – carried out with each student individually;
- 2) collective and/or group reflection.

The literature also includes other classifications of reflection, such as reflection on mood and emotional state, reflection on activity, reflection on the content of educational material, etc.

The study of the topic “Oxygen-containing organic compounds” is carried out in the 9th grade of the general secondary school, as well as in the 10th grade of the senior school at the standard and profile levels. In the 9th grade, the curriculum provides for a more introductory study of the topic “Oxygen-containing organic compounds”, in particular, the study of the main chemical categories on the topic (“alcohols”, “carboxylic acids”, “fats”, “carbohydrates”), characteristics of their chemical and physical properties, features of application in human life, impact on the natural environment, etc.

Already in the 10th grade at the standard level and in the specialized school, the topic “Oxygen-containing organic compounds” is studied in a more expanded way, and in the specialized school – in depth, in particular, each group of oxygen-containing organic compounds is studied separately.

An analysis of the content of the topic “Oxygen-containing organic compounds” studied in grades 9-10 is presented in table 1.

3. Methodology

To study the state of the problem of organising students’ reflective activity, a survey was conducted among 28 chemistry teachers of secondary schools in the city of Kryvyi Rih (Ukraine).

Teachers were asked to answer the following questions:

1. What is your teaching experience?
2. In what grades do you teach chemistry?
3. Do you consider reflection a necessary condition for creating a developing environment in chemistry lessons?
4. Among the functions of reflective activity in chemistry lessons in high school, choose the most important ones:
 - diagnostic
 - communicative
 - design
 - corrective
 - motivational
 - Your own answer _____
5. In your opinion, as a result of reflective activity in chemistry lessons, students learn:
 - to think critically
 - to formulate conclusions
 - to determine the purpose of their own activities
 - to argue their own opinion
 - to evaluate their own educational activities
 - to evaluate their emotional state

Table 1. Analysis of the content of the topic “Oxygen-containing organic compounds” (grades 9-10).

Grade	Content of the topic	Student competencies
9th grade	1) “Concept of alcohols, carboxylic acids, fats, carbohydrates”. 2) “Methanol, ethanol, glycerol: molecular and structural formulas, physical properties. Combustion of ethanol. Qualitative reaction to glycerol”; “Toxicity of methanol and ethanol. The detrimental effect of alcohol on the human body”. 3) “Ethanoic (acetic) acid, its molecular and structural formulas, physical properties. Chemical properties of ethanoic acid: electrolytic dissociation, effect on indicators, interaction with metals, alkalis, salts. Application of ethanoic acid. Higher carboxylic acids: stearic, palmitic, oleic. Soap, its composition, washing action”. 4) “Fats. Composition of fats, physical properties. Natural and hydrogenated fats. The biological role of fats”. 5) “Carbohydrates: glucose, sucrose, starch, cellulose. Molecular formulas, physical properties, distribution and formation in nature. Starch and cellulose are natural polymers. Qualitative reactions to glucose and starch. Application of carbohydrates, their biological role”.	1) knows the essence of the concept of “Oxygen-containing organic compounds” and can distinguish them by qualitative composition; 2) can name the most important oxygen-containing organic compounds; 3) can give examples of alcohols, carboxylic acids, fats and carbohydrates; 4) can compose molecular formulas of oxygen-containing organic compounds (glucose; starch; cellulose; glucose; sucrose; ethanoic acid; etc.); 5) can distinguish oxygen-containing organic compounds by composition and compare them with inorganic substances; 6) can characterize the composition and physical properties of oxygen-containing organic compounds, determine some of them by conducting chemical experiments, solve chemical problems and equations; 7) can justify the role of oxygen-containing organic compounds in living nature and human life.
10th grade (standard level)	1) “Alcohols. The concept of a characteristic (functional) group. Hydroxyl characteristic (functional) group. Saturated monohydric alcohols: general and structural formulas, isomerism, systematic nomenclature”. 2) “Chemical properties of saturated monohydric alcohols. Production of ethanol”. 3) “The concept of polyhydric alcohols on the example of glycerol, its chemical properties”. 4) “Phenol: composition and structure of the molecule, physical and chemical properties”. 5) “Aldehydes. Composition, structure of aldehyde molecules. Aldehyde characteristic (functional) group. General and structural formulas, systematic nomenclature and physical properties of aldehydes”. 6) “Chemical properties of ethanal, its production”. 7) “Carboxylic acids, their distribution in nature and classification. Carboxyl characteristic (functional) group. Composition, structure of molecules of saturated monobasic carboxylic acids, their formulas, systematic nomenclature and physical properties”. 8) “Chemical properties of saturated monobasic carboxylic acids. Esterification reaction”. 9) “Production of ethanoic acid”. 10) “Esters, general and structural formulas, systematic nomenclature, physical properties. Hydrolysis of esters”. 11) “Fats as representatives of esters. Classification of fats, their chemical properties”. 12) “Carbohydrates. Classification of carbohydrates, their formation and distribution in nature”. 13) “Glucose: molecular formula and its open form. Chemical properties of glucose”. 14) “Sucrose, starch and cellulose: molecular formulas, hydrolysis”.	1) knows and names (including by systematic nomenclature) the general formulas and functional groups of alcohols, aldehydes, esters, carboxylic acids; 2) can explain the peculiarities of the influence of the functional group on the physical/chemical properties of oxygen-containing organic compounds; 3) can give examples of oxygen-containing organic compounds and their trivial names; 4) possesses knowledge about the peculiarities of the distribution of oxygen-containing organic compounds in nature and food products; 5) can distinguish fats, monosaccharides, disaccharides and polysaccharides, as well as esterification reactions; 6) can compose formulas of oxygen-containing organic compounds and solve equations of reactions that describe the chemical properties of various oxygen-containing organic compounds; 7) can compare compounds with different characteristic groups in terms of structure and properties (physical/chemical); 8) establish cause-and-effect relationships between composition, structure, properties, application and impact on the environment of oxygen-containing organic compounds, as well as genetic relationships between them; 9) can solve experimental problems and equations.

- to evaluate the educational activities of other students
- to navigate the educational material of different levels of complexity
- to use equipment, laboratory glassware
- to evaluate the results of their own activities in the lesson
- Your own answer _____

6. The organisation of students' reflective activity in chemistry lessons allows the teacher to:
- compare the real results of their own pedagogical activity with the expected ones
 - formulate questions for discussion with other participants of the educational process
 - determine the level of students' knowledge
 - understand the students' mood
 - correct the knowledge acquired by students
 - analyse the success of the lesson
 - correct the practical skills acquired by students
 - adjust their own educational activities
 - determine the level of students' skills
 - make a plan for further pedagogical actions
 - understand what students have realised or assimilated from the educational material
 - Your own answer _____
7. In your opinion, in which types of lessons is it appropriate to organise students' reflective activities?
8. At what stages of the lesson, in your opinion, is it appropriate to organise reflection?
- Organisational moment
 - Checking homework
 - Motivation of educational and cognitive activity
 - Announcement of the topic, purpose, and tasks of the lesson
 - Control and correction stage
 - Summing up the lesson
 - Study (primary assimilation) of new material
 - Consolidation, systematisation and generalisation
 - Your own answer _____
9. Do you organise students' reflective activities during lessons?
- Yes
 - No
 - I do not use it, but I plan to

A number of questions in the questionnaire are designed for teachers who organise students' reflective activities during chemistry lessons:

10. What types of reflective activities do you use when conducting chemistry lessons to achieve the desired result?
- reflection of mood and emotional state
 - reflection on the content of educational material
 - reflection on comprehension of the activity
 - reflection on the design of activities
 - reflection on the regulation of activities
11. In your opinion, what factors influence the effectiveness of reflective activity in learning?
12. What forms or techniques of reflective activity do you implement during chemistry lessons?
13. What strategies do you use to improve the organisation of students' reflective activities in chemistry lessons?
14. During reflection in chemistry lessons, students have the opportunity to...
15. Do you organise students' reflective activities when studying the topic "Oxygen-containing organic compounds"?

The survey results showed that 25 teachers (89.3%) consider reflection a necessary condition for creating a developing environment in chemistry lessons. Among the most important functions of reflective activity in chemistry lessons in high school, they identified diagnostic and communicative (26 people or 92.85%), motivational (14 people or 50%), design (12 people or 42.85%), and corrective (10 or 35.71%).

When answering the question about the results of reflection during chemistry lessons, teachers noted that systematically organised reflective activity contributes to the formation of critical thinking in students, teaches them to analyse the obtained educational results, argue their own opinion or position, evaluate the results of their own activity in the lesson. At the same time, 7 of the respondents consider it inappropriate to organise reflective activities during students' laboratory work and to evaluate the results of classmates' educational activities. Another 10 (35.71%) of the respondents do not agree with the idea that reflective activity helps students navigate educational material of varying complexity and critically evaluate their own emotional state. At the same time, 25 (89.29%) of the 28 respondents agree that the organisation of reflective activity in chemistry lessons allows the teacher to determine the level of students' skills, formulate questions for discussion with students, adjust their own pedagogical activity, analyse the success of the lesson. 16 teachers, which is 57.13% of the respondents, do not consider reflection a means of strengthening interaction between participants in the educational process and an effective tool for correcting students' knowledge or skills.

Studying and analysing teachers' responses gives grounds to assert that only 50% of respondents systematically organise students' reflective activities during chemistry lessons. To the question "Do you organise students' reflective activities when studying the topic "Oxygen-containing organic compounds"?" only 4 out of 28 respondents, which is 14.28%, gave a positive answer. The survey also revealed the limited forms of organising students' reflective activities, which are reduced to reflection on the emotional state of students and comprehension of students' activities through questioning.

4. Results and discussion

Based on the results of the survey, lesson plans, instruction cards for laboratory and practical work, and video experiments with elements of students' reflective activity were developed that can be used in the practice of chemistry teachers.

Lesson plan fragments with reflective elements for Grade 9:

Topic: Physical properties of acids. Chemical properties of acids: effect on indicators, interaction with metals, basic oxides, bases, salts.

Stage: Generalization of knowledge

Reflective technique "Microphone" (reflective comprehension of the content)

- Are you familiar with polybasic acids?
- Name the physical properties of glycerol.
- What do polybasic acids react with?
- Describe the qualitative reaction for glycerol.

Topic: Carboxylic acids. Ethanoic acid, its molecular and structural formulas, physical properties

Stage: Motivation of educational and cognitive activity

Game situation "YES or NO?" (reflection on the content of the educational material)

The task for students: Among the proposed statements, find the correct ones and write down the numbers of the correct statements.

- carboxylic acids contain one or more carboxyl groups -COOH in their composition;

- according to the number of functional groups, carboxylic acids are divided into cyclic, aliphatic and acyclic;
- citric acid belongs to higher carboxylic acids;
- the sour taste of fruits and leaves of many plants is due to various carboxylic acids;
- the simplest carboxylic acid is formic;
- butyric acid is formed when butter rots;
- higher carboxylic acids are ethanoic and butanoic acids;
- the roots of the valerian plant contain a certain amount of butyric acid;
- sodium stearate and sodium palmitate are the main components of soap;
- one of the chemical properties of carboxylic acids is their interaction with insoluble bases.

Topic: Practical work No. 5. Detection of organic compounds in food products

Stage: Summing up the lesson

Exercise “Snowball” (reflection on the content of educational activity, students take turns answering questions. There is a moment of discussion):

1. Answer the questions:

- Where in nature is starch found?
- Where in nature is cellulose found?
- Where in nature is glucose found?
- What is the name of the “starch” produced by the human body?
- What kind of glucose is not assimilated by the human body?
- What is the biological significance of cellulose?
- What is the biological significance of lactic acid fermentation?

Lesson plan fragments with reflective elements for Grade 10:

Topic: Carbohydrates: glucose and sucrose. Molecular formulas, physical properties, distribution and formation in nature. Qualitative reaction to glucose

Stage: Perception and initial comprehension of educational material

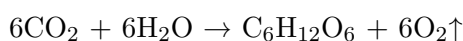
Exercise “Fishbone” (reflection on the content of educational material)



Figure 2. Fishbone diagram for studying the process of photosynthesis.

- What is this process called?
- What conditions are necessary for Photosynthesis to occur?

Write down the equations of the corresponding reactions:



Stage: Generalization and systematization of knowledge. Practical part
Interaction of glucose with freshly prepared copper (II) hydroxide

Task for students: watch the video of the experiment, write down the equations of chemical reactions, analyze the properties of glucose and draw conclusions. Glucose gives qualitative reactions to polyhydric alcohols and aldehydes, therefore, its molecule contains hydroxyl groups and an aldehyde group.



Figure 3. Demonstration: Interaction of glucose with copper (II) hydroxide.

Exercise “Take a position” (collective-group reflection of activity).

Problem question: How are the properties of glucose classified? Describe the properties that belong to each group. Confirm your answer with the equations of the corresponding chemical reactions. Activity stages of each group of students: position. “I believe that ...”; justification; example of reaction equation; conclusion “I think so because...”.

The developed methodological kits aim to increase students’ interest in the subject, encourage the search for information, deepen students’ knowledge, and apply information and communication technologies in teaching.

The results of the survey of teachers on the use of reflective activities in chemistry lessons are presented in table 2.

Table 2. Results of the survey of teachers on the use of reflective activities in chemistry lessons.

Question	Teachers’ answers
Do you consider reflection a necessary condition for creating a developing environment in chemistry lessons?	Yes – 89.3% No – 10.7%
Among the functions of reflective activity in chemistry lessons in high school, choose the most important ones	Diagnostic and communicative – 92.85% Motivational – 50% Design – 42.85% Corrective – 35.71%
Do you organise students’ reflective activities during lessons?	Yes - 50% No - 50%
Do you organise students’ reflective activities when studying the topic “Oxygen-containing organic compounds”?	Yes – 14.28% No – 85.72%

The analysis of scientific and methodological literature made it possible to distinguish the

main types of reflective activities that are advisable to introduce in chemistry lessons when studying the topic “Oxygen-containing organic compounds” (figure 4).

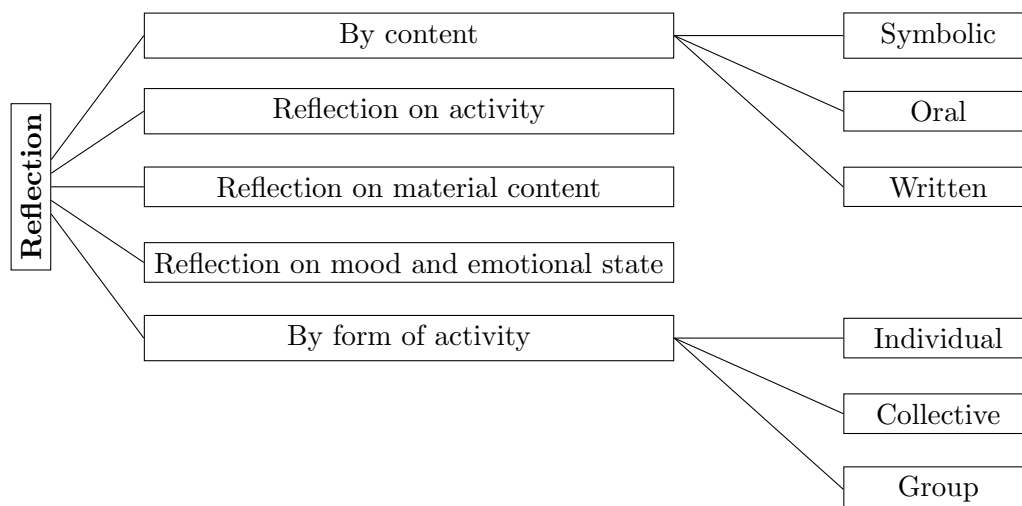


Figure 4. Types of reflective activity in chemistry lessons.

5. Conclusions

Within the context of European integration processes in education, there is an increasing need for new educators who are not only capable of clearly formulating and effectively solving specific didactic tasks in teaching (transmitting educational information, organizing the process of its qualitative assimilation, assessing the level of students' knowledge and skills, etc.), but also act as active agents of professional activity based on the principles of pedagogical partnership, learner-centered, and competency-based approaches. In this context, reflective activity plays an important role, aimed at ensuring self-design and creative development of both the teacher's and the students' personalities.

From the perspective of pedagogical practice, reflection constitutes an intellectual and emotional activity through which a teacher analyzes his or her teaching experience to achieve high-quality learning outcomes for a student. To acquire the competencies necessary for successful social integration, personal growth, and professional activity in adulthood, a student must already in school learn to independently obtain information, formulate and, through discussion, defend his or her own position, and collaboratively solve specific problems. Reflection serves as a system-forming factor in organizing thinking, activity, and communication.

Today, high-quality chemistry teaching cannot be realized without the use of tools and opportunities provided by reflection, especially when introducing students to complex chemical material that includes a large number of terms and chemical reaction equations. The application of various types of reflection (emotional, related to the content of educational material, and related to activity) in chemistry instruction enables the teacher to: compare actual educational outcomes with the predicted ones, identify key topics for discussion with students, develop their motivational sphere, cognitive activity, and mobility, and to adjust what has been learned by students. It also enables students to: reconsider their own experience of studying chemistry, deepen their theoretical knowledge, improve their skills, develop intellectual capacity, independence, and creativity, and enhance their level of self-development and self-education.

The study of the basic classes of inorganic compounds occurs throughout the entire school chemistry course, with the main volume of knowledge acquired in the 8th grade. Due to technical

and methodological difficulties, Ukrainian teachers face challenges in using reflective activities to study this topic.

This study analysed teachers' experiences in organising students' reflective activities and revealed the limited use of reflective activities, which are reduced to reflection on the emotional state and comprehension of students' activities through questioning.

Based on the survey results, lesson plans, instruction cards for laboratory and practical work, and video experiments with elements of students' reflective activity were developed that can be used in the practice of chemistry teachers.

The developed materials aim to increase students' interest in the subject, encourage the search for information, deepen students' knowledge, and apply information and communication technologies in teaching.

It has been established that the systematic diagnostics and constant monitoring of students' competencies, adjusting the learning process through reflection, and creating a trajectory for the development of students' reflective processes will help overcome educational losses and improve the study of the subject "Chemistry" in secondary school.

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Principles and methods of integrating geospatial analysis into the school geography course

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Abstract. Geoinformation analysis is associated with the search for spatial patterns and relationships in the distribution of geographical objects, processes, and phenomena, resulting in new geoinformation that is of high practical importance. The use of geospatial analysis in the educational context includes several key components and approaches that help to make traditional geography lessons in the school curriculum more modern, effective, and interesting. The main principles of implementing geospatial analysis in a school geography course using various methods and technologies for research, analysis and visualization of geographic data are developed.

1. Introduction

Today, geographic information technologies are considered as an effective tool for understanding geographic space. According to most researchers, its use makes it possible to study and analyze the spatial differentiation of various processes, objects and phenomena, which solves practical problems in various fields of human activity: ecology, agriculture, transport, urban planning, etc. [1]

Geoinformation technologies are especially important in the educational process. Teaching based on these technologies makes it possible to study the peculiarities of spatial changes in natural and anthropogenic objects, processes and phenomena, i.e., to conduct geospatial analysis. This not only develops students' digital competencies and skills, but also significantly deepens their general and geographical knowledge [2].

Geospatial analysis is the process of applying analytical methods and tools to study geospatial data, identify trends and relationships. It is closely related to geospatial thinking. Geospatial thinking provides the cognitive framework for understanding geographic concepts, and geospatial analysis provides the tools and techniques to explore geospatial data. Together, they create a powerful set of skills for solving a variety of spatial geographic problems.

Currently, there are no national or state standards for spatial thinking content course [3]. Consequently, there is no incentive to advance educational materials to develop students' skills in geospatial thinking and, consequently, in geospatial analysis. However, in twentieth-century global educational practice, one can find examples of projects in which enthusiasts have



developed GIS-based resources that can be used to introduce geospatial analysis into the existing school geography curriculum.

For example, the Saguaro project has developed modules on cyclones, hurricanes, and the dynamic Earth. The KanCRN project provides two modules: one spatially links tornadoes and the mean position of the jet stream, and the other studies leaf samples to estimate ozone levels. ESRI has developed lessons for teachers that use ArcGIS to explore various aspects of spatial analysis of the geographic envelope.

The active introduction of geospatial research into the practice of modern schools began in the early 21st century. Indeed, the fundamental research of George Kerski [4] showed that geospatial analysis in various forms can be used at all levels of primary and secondary education, however being more effective in high school. Further research [5–10] was aimed at developing the theoretical and practical component of geospatial analysis in the educational process using GIS.

According to several authors, GIS can be a useful tool to help students develop their spatial abilities and solve spatial problems, develop their spatial reasoning, improve their map-related skills, and enhance their critical thinking, communication, and analytical skills [11]. But besides GIS, Earth remote sensing (RS) data can also be a technology to improve students' spatial reasoning concepts. Remote sensing provides real-world data that allows you one to analyze natural disasters or other phenomena in reality [12]. Also in addition, Flynn [6] proved that the use of educational geocaching in the learning process has improved certain areas of spatial thinking in students.

Today, most scientists [13–15] are convinced of the need to introduce geospatial analysis into school geographic education, which, in their opinion, will improve the quality of geography learning and promote a deeper understanding of the phenomena and processes of the geographic environment. This, in turn, requires technological, logistical, pedagogical and administrative support. As noted by Kerski, technological problems include Internet bandwidth, availability of spatial data, and the cost of software [4]. Logistical support includes building the necessary hardware (computers, interactive whiteboards, scanners, etc.). Pedagogical challenges include teaching using web-based geospatial analysis tools and the necessary methodological materials [16, 17]. Administrative issues such as competition for teaching time and funding create additional obstacles to the introduction of geospatial technologies in the educational process.

This is confirmed by experiments that have been conducted in schools around the world when teaching geography. For example, van der Schee et al. [18] conducted a series of three geography lessons for students of one class using geospatial analysis, and for another class – in the traditional form of presentation of the material. Tests conducted at the end of the experiment demonstrated that lessons with geospatial technologies contribute to a much deeper learning of the educational material.

Thus, the issue of using geospatial analysis in the educational context is of high theoretical and practical importance, which confirms the relevance of this study.

The objective of the study is to define and substantiate the principles and methods of integrating geospatial analysis into the school geography course.

2. Results and discussion

Geospatial analysis exists at the interface between humans and computers. Both play a key role in it – on the one hand, human intuition, and on the other hand, formal and mathematically accurate calculation of geospatial data. Therefore, the teacher's task is to ensure effective and comfortable interaction of students with computers within the framework of the school geography course program.

Based on the analysis of scientific and methodological literature as well as on our own experience, we have formed the main principles of introducing geospatial analysis into the school

geography course:

1. It is important that geospatial analysis is not viewed as an addition to an already overcrowded school curriculum, but as a technology in the curriculum that helps to look at traditional course material in a completely new way. Thus, geospatial technologies should be integrated into existing topics of the school geography course, which contributes to a deeper learning of the material, development of analytical skills and preparation of students to solve real problems related to geospatial data analysis.

The analysis of the content of the school geography course leads to the conclusion that it is possible to integrate geospatial analysis for most of the course topics. Here are a few examples of how geospatial analysis can be used in geography classes:

- *Studying demographic trends.* Students can use geospatial analysis to examine population density, age group distribution, ethnicity, or urbanization in different regions. This could be related to migration or historical trends.
- *Exploring environmental issues.* Students can analyze the spread of air pollution in a city or measure the decline in forest cover in a particular region.
- *Geography of biological resources.* Geospatial analysis can be used to study the distribution of distinct species of plants and animals, their habitats, and the environmental factors that affect their distribution.
- *Climate data analysis.* Students can use geospatial analysis to examine climate data such as temperature, precipitation, or climate change over time. This could be related to the study of global warming, meteorological phenomena, or the impact of climate on agriculture.
- *Study of mineral resources.* Geospatial analysis can be used to explore the relationship between the location of a mineral deposit and the geological structure of a region.

For example, figure 1 shows a model of a map with an overlay of layers of earthquake locations with a magnitude of more than 5.7 and the boundaries of the Earth's tectonic lithospheric plates, created by students when studying the topic "Lithosphere" in the school course "General Geography" (grade 6).

Its analysis allows the teacher to illustrate the following conclusions for students:

- the largest earthquakes with a magnitude of more than 8 are localized in subduction zones of convergent lithospheric plate boundaries (the Pacific Ring of Fire, Chile, Japan, Indonesia, etc.);
- most strong earthquakes occur along the boundaries of the Pacific Eurasian and Indian lithospheric plates;
- intraplate earthquakes are rare and usually associated with ancient faults in the lithosphere.

Exploring the connection between earthquake localization and plate boundaries allows students to better understand the mechanisms of seismic events.

It is of particular interest to use geospatial technologies in various practical activities. In this case, it becomes possible to conduct classes based entirely on geospatial analysis using mapping services such as *Google Earth*, *OpenStreetMap*, *ArcGIS Online*, etc. This will allow students to explore geographic objects and phenomena on their own.

2. One of the key elements of introducing geospatial analysis into the school geography course is **working with real geospatial data**. This makes learning more interactive, relevant, and focused on the practical application of knowledge, which contributes to the comprehensive development of students.

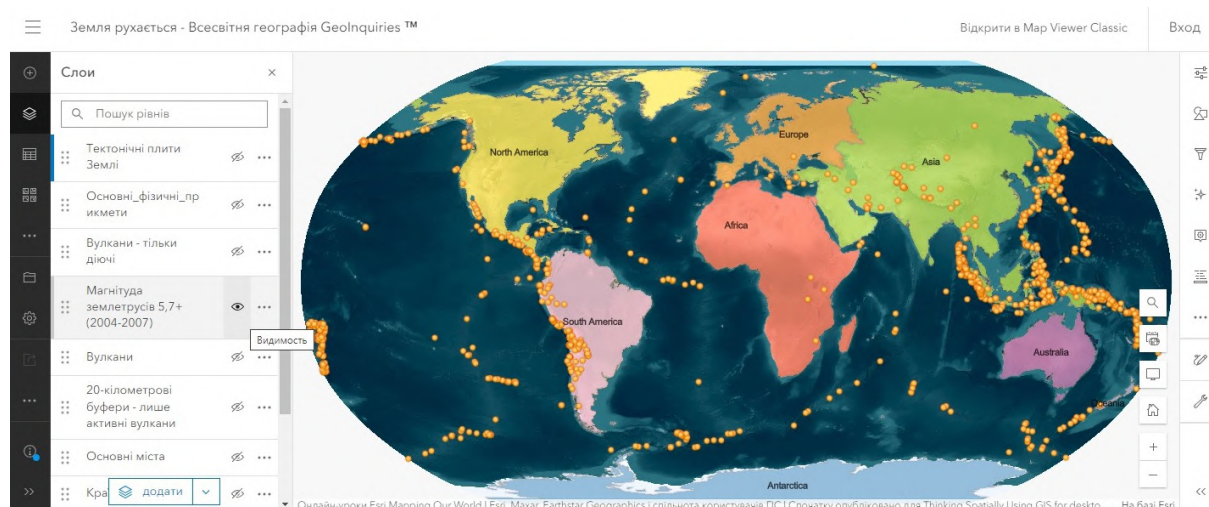


Figure 1. Map with overlay of layers of earthquake locations with magnitude greater than 5.7 and boundaries of tectonic lithospheric plates of the Earth (obtained using the GeoInquiries platform).

For this purpose, students can use geodata from various sources. First, these are various international and national statistical databases (*NASA Earth Observing System Data and Information System*, *GeoNetwork*, *WHO*, *Ukrstat*, etc.), mapping databases (*Google Earth*, *OpenStreetMap*, *Natural Earth*, *GISFile*, etc.).

Students can also collect geospatial data on their own during field research. This may include measuring environmental parameters, using GPS devices to collect location data, taking photos and recording objects on the ground [19]. It is interesting to collect data through interviews/questionnaires with residents, which can be part of projects related to social or economic geography.

Students can use GIS to analyze the collected data and create their own thematic maps that reflect the phenomena under study (for example, a map of the distribution of certain plant species, a map of natural disaster risks, a map of the socio-economic development of the region, etc.)

Figure 2 shows an example of a map built by students from the Kentucky College of Agriculture, Food and Environment based on detailed long-term observation of the distribution of fires in the Kingdom Come Park. Based on the results of the geospatial analysis, the fires were linked to the distribution of certain types of vegetation.

Spatial research is also possible without the use of GIS. But in this case, the tasks should be simplified. Here are some examples:

- *A map of the local environment showing biodiversity.* Students can collect data on biodiversity in the study area (e.g., trees, including their species, height, and trunk diameter). Then, they can draw a map labelling the identified features and adding photos (figure 3).
- *Pollution map around the school.* Students can research noise, air, and water pollution in the school's vicinity and create a map that shows the level of pollution at different points.
- *A map of students' routes to school.* Students can record their routes to school on a bicycle using a GPS tracker and then create a map with the routes and dangerous areas marked.
- *Map of sports fields and recreation areas in the neighbourhood.* Students can study the existing sports fields and recreation areas in their neighbourhood and create a map with

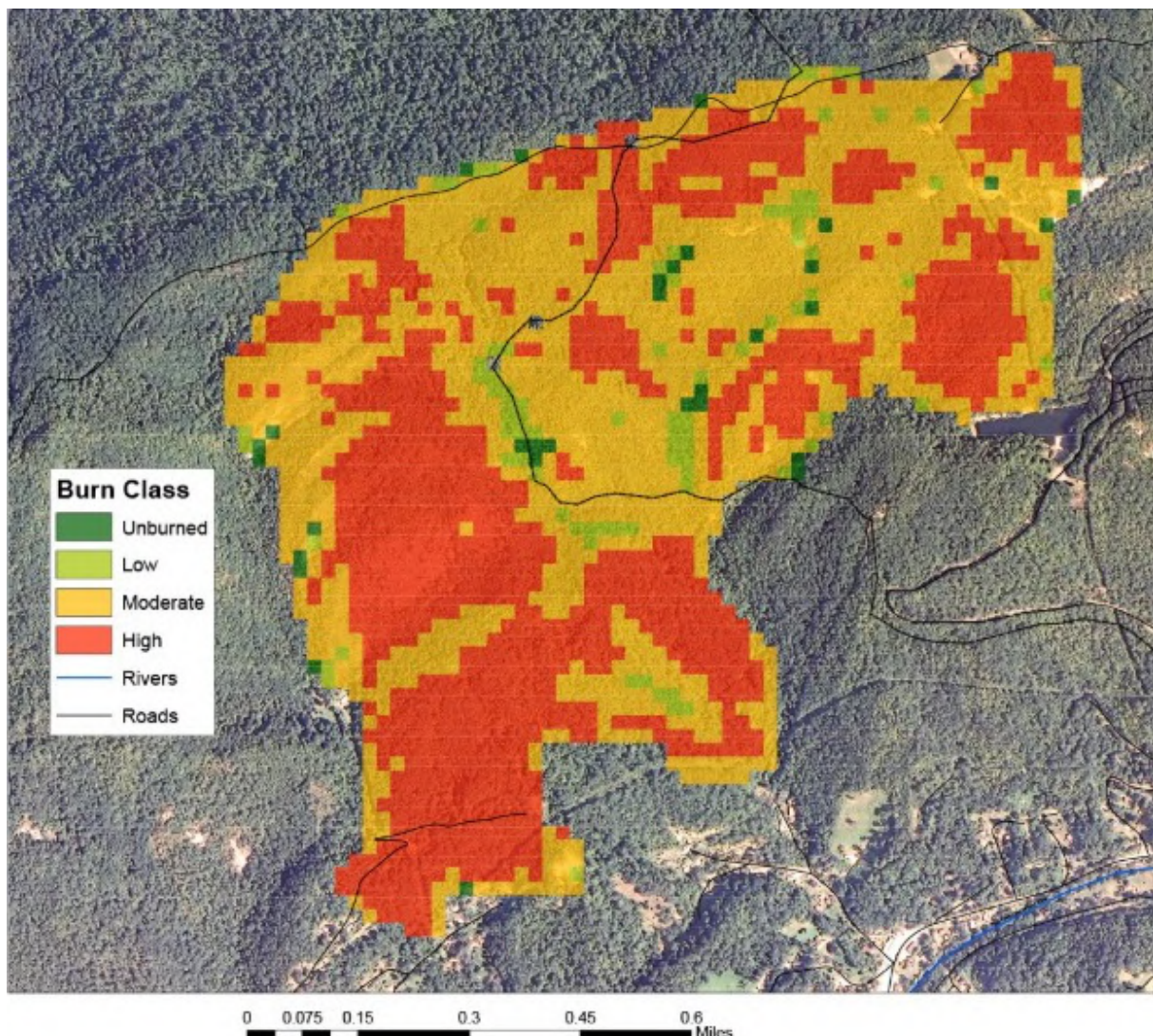


Figure 2. Analysis of forest fires in the Kingdom Come Park (according to https://geography.as.uky.edu/sites/default/files/FOR330_KyleHoward_Fall2014_FinalProject.jpg).

their locations and descriptions.

- A map of where students in the class live, showing their favourite places in the neighbourhood. Students can create a map showing their homes and add labels for their favourite places in the neighbourhood, such as parks, cafes, or shops (figure 4).

Involving students in researching and solving real-world problems in their local area or region helps to increase motivation and demonstrates the practical value of geospatial analysis.

3. The development of project activities in the implementation of geospatial analysis in the school geography course is an effective means of activating the learning process, developing critical thinking, and forming skills in working with modern technologies. Project activities allow students to apply the acquired knowledge in real-life situations and contribute to the development of skills of cooperation, research and presentation of results.



Figure 3. An example of mapping the biodiversity of the local environment (according to <https://www.heritageinschools.ie/online-tutorials/how-to-make-a-biodiversity-map-of-your-garden>).

When planning projects, students should have a clear plan for project implementation, including the definition of the goal, objectives, research methods, distribution of responsibilities in the group and setting deadlines. Various sources can be used to collect geospatial data, such as maps, satellite images, statistics, surveys, and field research. Analyzing this data allows you one to gain new knowledge and draw reasonable conclusions.

Working in groups develops students' cooperation skills, the ability to resolve conflicts and make joint decisions. Presentation of results teaches students to communicate effectively and present their work.

An example of such work is the research conducted by students in grades 10-12 at Bishop Dunne Catholic School in Dallas, Texas [3]. After receiving data from the police department on robberies in the region for a certain period, the students geocoded the locations of robberies, identified hotspot areas, and created maps of robberies. The students then analyzed the geographical patterns and made recommendations to the police department regarding the patrolling area. The result was a reduction in crime in the study area.

Here are some more possible examples of projects:

- *"Monitoring the condition of green areas in the city"* – using satellite images to analyze changes around green areas and assess the impact of urbanization on the city's ecology;
 - *"Transport infrastructure research"* – building maps of road density in the region and assessing the accessibility of social facilities;
 - *"Energy map of the region"* – studying the location of alternative energy facilities in the region and analyzing the efficiency of their use.
4. A powerful tool to support geospatial analysis is geographic information systems (GIS), as they provide collection, storage, processing and visualization of geographic data. GIS combines spatial technologies with statistical and spatial analysis tools to perform analytical

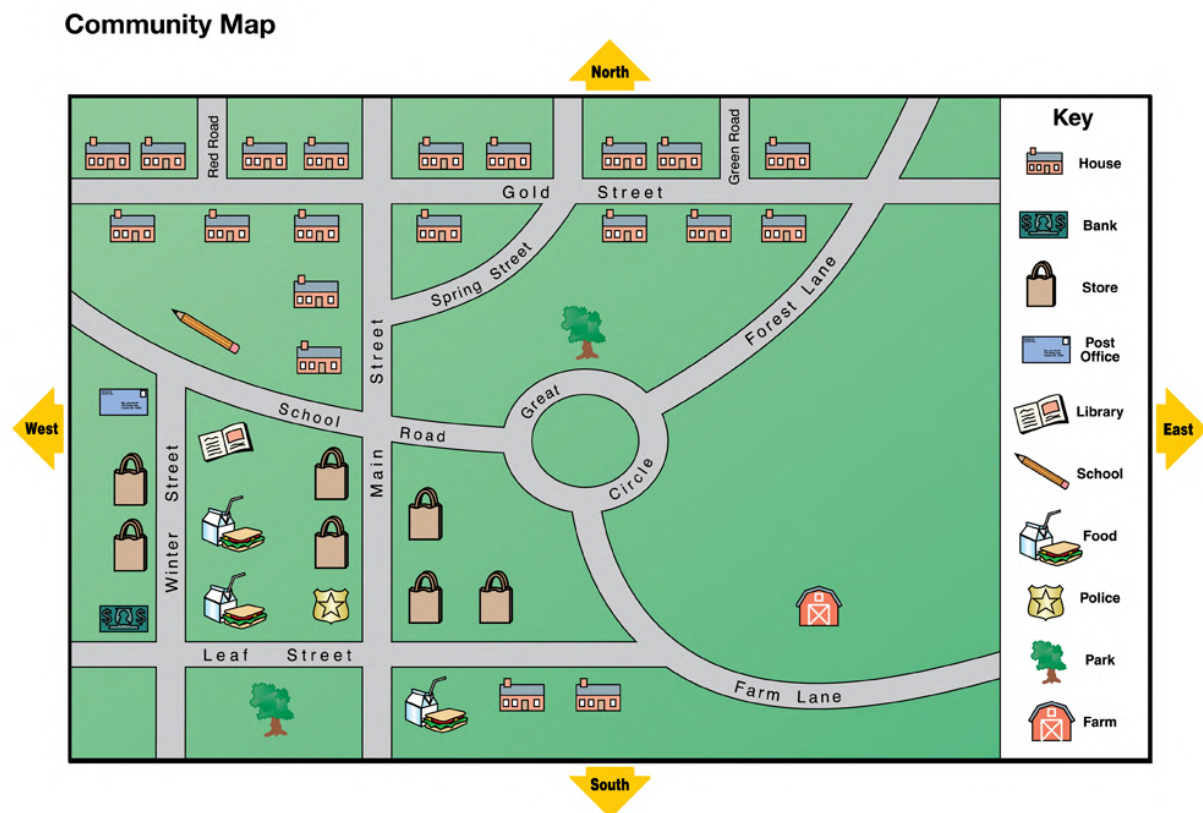


Figure 4. A map of students' places of residence showing their favorite places in the district (based on <https://images.nationalgeographic.org/image/upload/v1638889251/EducationHub/photos/community-map.jpg>).

functions by manipulating and visualizing the structural relationships between spatial geodata sets.

Introducing GIS into the educational process requires appropriate teacher training and technical resources, but the results, such as improved geospatial thinking, justify the effort. Introducing students to GIS should be gradual. Initially, one can use online maps and tools from various educational web platforms, such as *MapMaker Interactive*, *GeoInquire*, *Google Earth*, etc. Most of these geo-resources are free or have educational licenses, which makes them accessible to schools. It is also important that they have pre-loaded geospatial data, which makes it possible to conduct geospatial analysis without additional steps. Some platforms even have developed standards-oriented lessons to integrate geospatial technologies into the learning process. For example, *ESRI's GeoInquiries* platform provides access to interactive web maps of various kinds that are designed to be used with *ArcGIS Online* without the need for a login or prior GIS experience (figure 1).

Teachers who have the appropriate training can subsequently transition to more complex software products such as ArcGIS, QGIS, MapInfo, etc. They allow for more complex and information-rich geospatial analysis tasks. For example:

- *Creation and analysis of current thematic maps.* With the help of GIS, students under the

guidance of a teacher can create maps that reflect various geographical phenomena, such as climate zones, population distribution, or economic activities, which will be based on the latest (in terms of time) geospatial data, particularly relevant for analyzing very dynamic processes and phenomena (e.g., external and internal population migration);

- *Establishing relationships in space and time between processes and phenomena* (for example, analyzing factors of spatial distribution of natural resources);
- *Analysis of transport infrastructure.* Students can assess the accessibility of various facilities, study the road network, determine the most optimal routes, and identify areas of concentration of traffic accidents (figure 5).

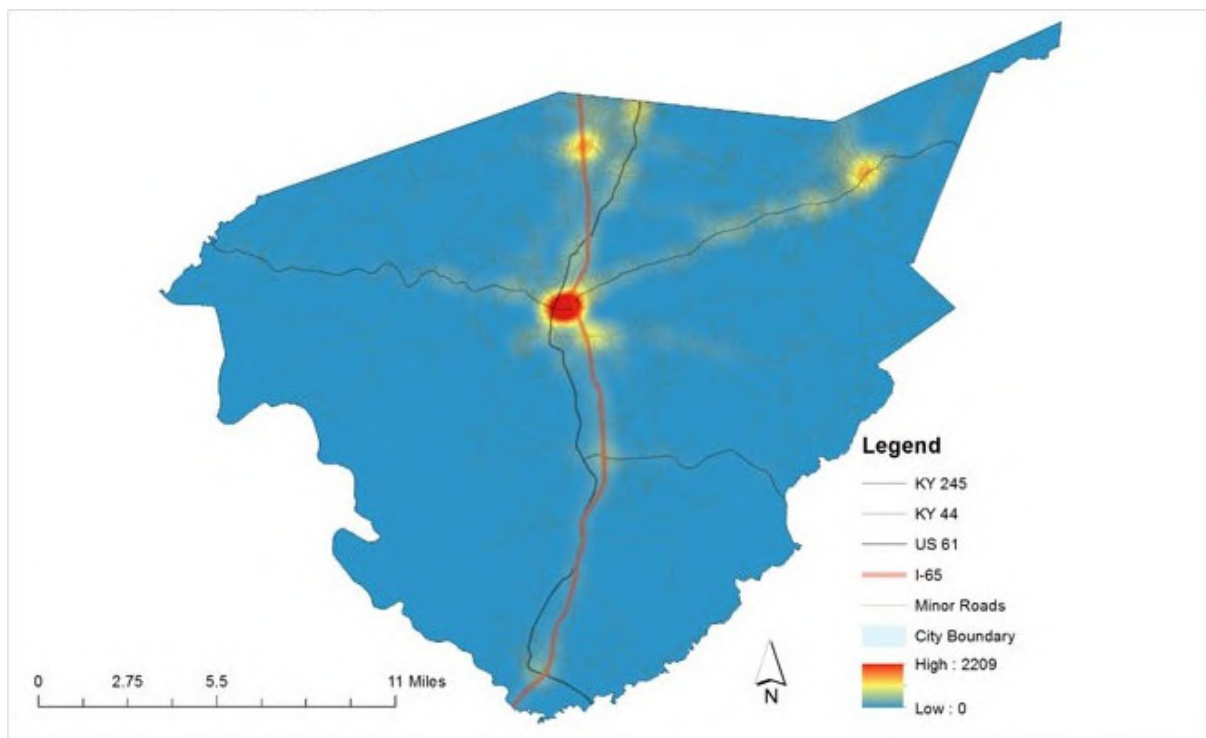


Figure 5. Map of the concentration of car accident locations, created by students at Bishop Dunne Catholic School in Dallas (based on data from https://geography.as.uky.edu/sites/default/files/NRE355_AustinSauer_Fall2014_FinalProject.jpg).

- *Modeling environmental risks.* GIS allows identifying areas prone to natural disasters such as earthquakes, floods, or landslides, and developing risk reduction plans;
- *Studying the terrain.* With the help of GIS, it is possible to model three-dimensional surfaces, analyze slope steepness, determine watersheds, and assess potential flood zones.

This is just a small list of geospatial analysis tasks that can be performed in the school geography curriculum using GIS.

5. However, geospatial analysis can be integrated not only into geography but also into related disciplines such as history, biology, economics, and mathematics [20]. This will contribute to the formation of **an understanding of interdisciplinarity and the significance of geospatial data in various fields**. An interdisciplinary approach to integrating geospatial

analysis into the school geography curriculum allows for the combination of knowledge and methods from various subjects, which contributes to a comprehensive understanding of complex phenomena and processes by students, as well as developing their analytical and research skills.

For example, students can use geospatial analysis to study biodiversity in different regions by analyzing data on species distribution, ecosystem status, and the impact of climate change on biological diversity. This approach helps to understand the interplay between natural and anthropogenic factors.

The integration of history with geography allows students to analyze historical maps, study changes in borders, migration processes, and so on. This contributes to understanding how historical events impact the geographical development of regions. Students can use geospatial analysis to study cultural objects, their locations, and historical changes in the landscape related to the cultural development of society.

6. The successful implementation of geospatial analysis in geography lessons requires fundamental professional training for teachers. Only well-prepared teachers are capable of effectively using geospatial analysis in the practice of modern schools.

Referring to the experience of Hauselt and Helzer [21], it is worth noting that quality training for future teachers can be achieved by including geospatial science in the curriculum for the professional preparation of modern geography teachers. Such education allows for the cultivation of a generation of young teachers who possess spatial knowledge, geospatial ways of thinking, as well as geospatial analysis technologies.

The professional development of teachers can be shaped through qualification enhancement courses (trainings, seminars, and webinars), collaboration with colleagues, participation in conferences, and so on. Most importantly, teachers can independently acquire new knowledge using Internet resources, textbooks, and literature on geospatial analysis and geography.

Despite all the advantages that teachers gain from integrating geospatial analysis into the school geography curriculum, today we have few examples of its use among practicing educators. Among the problems that hinder this process, the most significant are:

- *Limited number of hours in the school geography curriculum.* Existing geography curricula in most countries around the world do not include the use of geospatial analysis. Individual examples that can be found in the literature [3] are more of an exception than the rule.

As an option, it is possible to recommend integrating appropriate short tasks (15-20 minutes) of geospatial analysis into the existing topics of the school curriculum. For example, when studying population geography, students can use the *Map Viewer* cartographic application to create maps of demographic indicators for countries around the world (population size, density, child mortality rate, etc.). Spatial analysis of these indicators (figure 6) allows for the identification and explanation of spatial patterns, as well as the identification of factors that influence their differentiation.

- *Limited access to high-quality geospatial data adapted to educational needs.* Today, there are many sources of geospatial data available for conducting geospatial analysis. However, much of the freely available data is created for professional use and does not consider the knowledge level of school students. To address this, it is necessary to create simplified and theme-oriented datasets that are easy to understand and adapt to specific educational topics. Additionally, teachers must be able to assess the quality of these data, with key components including data completeness, logical consistency, positional accuracy, thematic accuracy, and temporal accuracy.

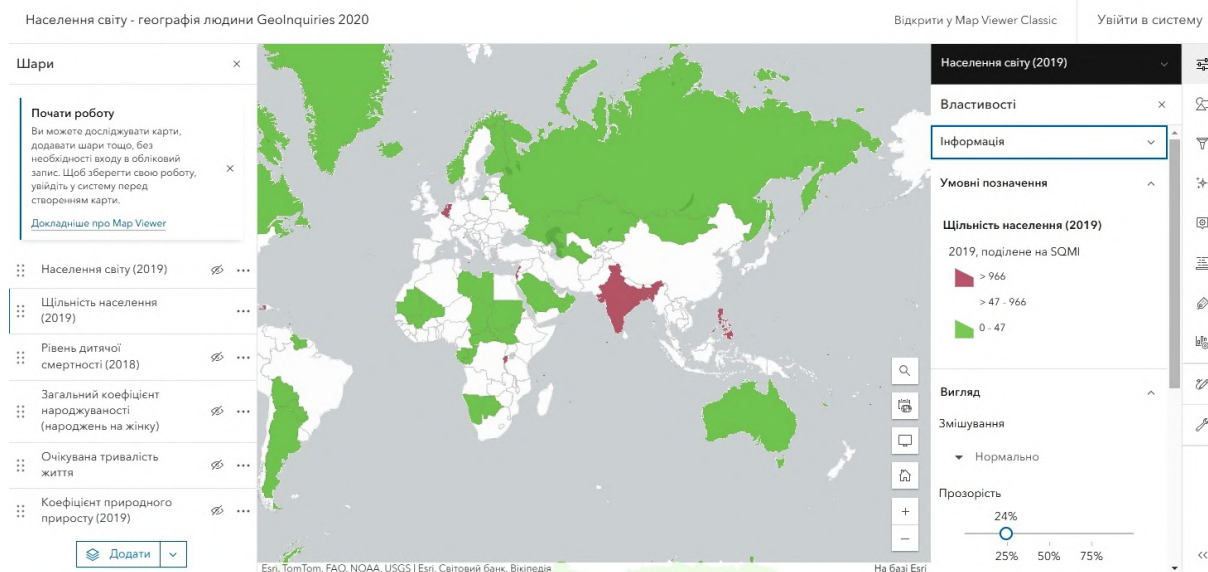


Figure 6. Population density map created on the educational platform GeoInquiries.

- *The lack of necessary methodological developments and appropriate textbooks.* The shortage of modern textbooks and manuals on the implementation of geospatial analysis in the educational process leads to teachers having to independently develop approaches to its integration, which can significantly reduce the effectiveness of learning. Organizing various courses and webinars for teachers on this issue can be considered one of the ways to address it.
- *Uncertainty of pedagogical teaching methods.* This is one of the main obstacles to the implementation of geospatial analysis in the educational process. To date, this issue remains insufficiently studied and developed.

As an example, let's consider some effective methods and technologies.

An effective means of integrating geospatial analysis into the school geography curriculum is interactive teaching methods, as they promote active student engagement in the learning process, the development of critical thinking, and analytical skills. Thus, students can use interactive maps such as *Google Maps*, *Google Earth*, and *OpenStreetMap* to study geographical objects and analyze spatial data. They can independently explore the terrain, change map layers, compare different time periods, or geographical regions.

Problem-based learning with geospatial analysis contributes to the development of students' ability to think spatially and understand the interconnections between various geographical processes and phenomena. The teacher should develop tasks that reflect real geographical problems, encouraging students to solve them using geospatial analysis. For example, the teacher asks the question: *What type of lithospheric plate boundary is characterized by the highest concentration of shield volcanoes?* Students should analyze the tectonic interactive map on the *GeoInquiries* platform (figure 7) and provide an answer.

An important role in the formation and development of geospatial thinking is played by gaming technologies, as they allow students to study spatial relationships between objects, phenomena, and processes in an engaging way. One example is geocaching – a geospatial game where students use GPS coordinates to find hidden “treasures” or objects in the terrain. This method promotes the development of navigation skills and the use of geospatial technologies in real-world conditions.

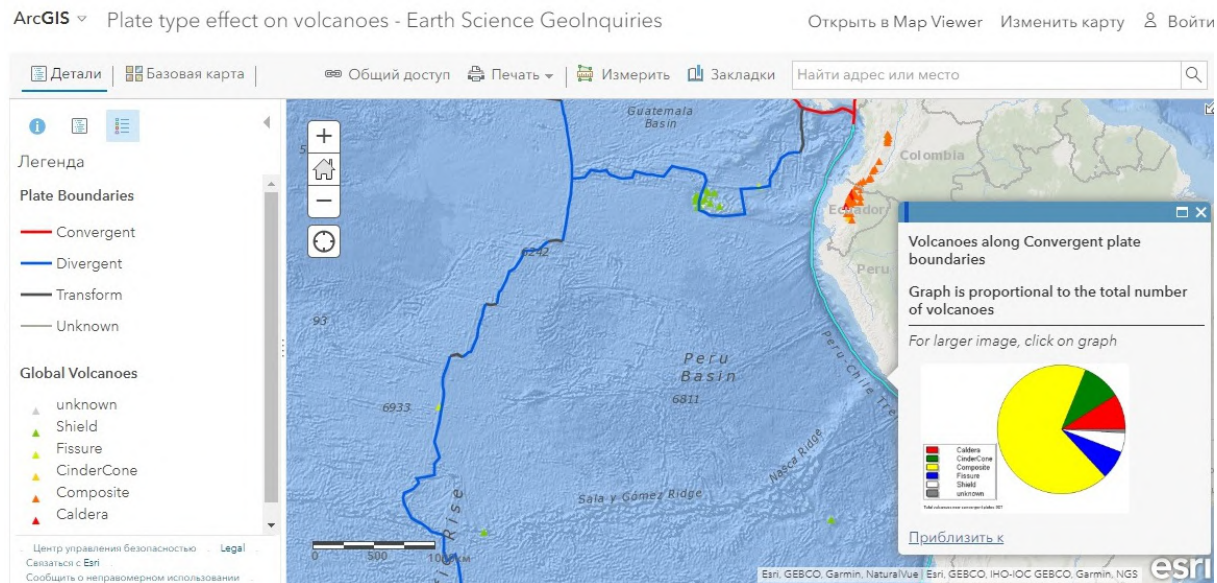


Figure 7. A tectonic map on the *GeoInquiries* platform with a summary chart showing the number and ratio of different types of volcanoes at 250 miles on both sides of the lithospheric plate boundaries.

A detailed analysis of the ways to overcome all these and other problems is a separate topic for consideration and is a direction for further research.

3. Conclusions

1. The use of geospatial analysis in an educational context includes a few key components and approaches that help make traditional geography lessons in the school curriculum more modern, effective, and engaging.
2. There is a need to include geospatial analysis in the school geography curriculum, which will ensure a deeper understanding of the various objects, processes, and phenomena of the Earth's geographic envelope.
3. The implementation of geospatial analysis in school practice is hindered by several problems that need to be addressed.
4. The main principles of implementing geospatial analysis into the school geography curriculum are:
 - geospatial technologies should be integrated into the already existing topics of the school geography curriculum;
 - geospatial analysis should be based on the use of real geospatial data;
 - the development of project activities is one of the most effective forms of integrating geospatial analysis into the school geography curriculum;
 - using GIS as a powerful tool for supporting geospatial analysis in the educational process;
 - an interdisciplinary approach is important when implementing geospatial analysis in the educational process;
 - for the successful implementation of geospatial analysis in school practice, geo-information training for teachers is necessary.

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Geospatial data in school geography courses: Sources, methodological features of use and implementation challenges

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Abstract. Geospatial data plays an important role in the formation and development of analytical and geospatial thinking in students, ensuring the practical application of knowledge and interactivity of learning. The article considers the advantages that a teacher gains through the use of geospatial data: improved visualisation of educational material, increased student engagement, individualisation of learning, formation of skills in working with geoinformation technologies, and access to a large amount of information. The main challenges faced by teachers in integrating geospatial data into the educational process are also examined and recommendations for overcoming them are provided. The main pedagogical methods and technologies for using geospatial information in the process of teaching geography are analysed.

1. Introduction

Today, geoinformation technologies are considered an effective tool in geographical education. Numerous studies by scientists and educators-practitioners (Bubyr, Zhernovnykova, Peretiaha, Kovtun, Korduban, Nalyvaiko, Nalyvaiko, Karpinsky, Lyashchenko, Gorkovchuk, Adanal, Bakillah, Liang, Belgiu, Strobl et al.) [1–22] have demonstrated that their use provides improved quality of learning, development of geospatial thinking, and integration of modern technologies into the educational process. As a result, this makes geography lessons more interactive, visual, and practical, which stimulates students' interest in studying the subject.

The key element in the implementation of geoinformation technologies in geography lessons is geospatial data, as it provides the ability to analyse complex processes and phenomena in space and time, which contributes to a deeper understanding by students of the interaction between natural and social systems.

As noted by one of the leading scientists in the field of geoinformation technologies, Kerski, limited access to data or their absence, heterogeneity of data formats and legal restrictions, the problem with quality and lack of adaptation to the educational process significantly limits the possibility of using geoinformation technologies in geography lessons [13].



In scientific and scientific-methodical literature, one can find examples of the use of educational geospatial data in geography courses of school programs in different countries of the world. So, in the work of Ridha et al. [20], the issue of creating educational materials that contain components of spatial thinking is discussed. According to the authors, if the teacher was the main source of learning earlier, other sources of information should be considered. This is especially relevant for distance learning. As such sources, it is recommended that information databases that provide the necessary geospatial data for their further use with the help of GIS be used.

This view is also supported by Deng et al. [11]. In their research, they emphasize that the active use of online educational sources of geospatial data has a positive impact on mitigating the problems of science education in the Earth science system and has the potential to promote deeper learning.

As an example of the possibilities of using online platforms as sources of educational geospatial data, they demonstrated how the *GeoBrain* online environment can serve as an accessible learning resource. This NASA-funded project is a geospatial web portal system capable of meeting the needs of educators in a variety of geospatial information.

Kira and Sumari [17] prove by their research that the successful implementation of geoinformation technologies in geography lessons largely depends on the created database of geospatial data on various topics. As an example of such an educational database, one can cite a collection of more than 800 satellite images created by scientists at Kryvyi Rih State Pedagogical University (Ukraine). In it, the images are grouped according to the principle of compliance with the requirements for educational resources, namely, their high information load and visibility. It includes a keyword search system, and for each image, its description is provided [16].

It is necessary to separately note the work of Doering [12], which is based on the understanding that geospatial technologies are a constructivist tool with which students can build their own knowledge using tools with authentic data. Using their own example, it was proved that very interesting and relevant geospatial data for their integration into the school curriculum can be obtained through their own observations in their region or during a trip.

Analyzing these and other articles in this direction, it should be noted that one of the main reasons for the slow integration of geoinformation technologies into secondary school classrooms has not yet been resolved - limited access to educational geospatial data and an unclear pedagogical model of their application in the educational process. Thus, solving this problem is an important challenge for educators. Finding ways to solve it forms the relevance of this work.

The **purpose of the work** is to develop principles and methods for using geospatial data when studying school geography courses.

2. Results and discussion

The world in which we live is inherently spatial. All objects, processes, and phenomena occur in a certain place, so their study necessarily involves determining their position in space at a certain time. Modern science uses geospatial data for this.

Today, in the scientific literature, there is no unambiguous definition of the concept of geospatial data (GSD). It varies from a rather simplified definition: "Geospatial data contains information about coordinates (for example, latitude and longitude), which allows mapping objects", which can be found on the Brandeis Library website (<https://guides.library.brandeis.edu/c.php?g=990410&p=7164688>), to a more capacious concept defined in the work of Layton and Watters: "Geospatial data combines information about location (usually coordinates on the Earth), attribute information (characteristics of the corresponding object, event or phenomenon), and often time information (time or duration of life during which the

location and attributes exist)” [18].

But still, most scientists emphasise [5–9, 14, 19, 21, 22] that geospatial data is more than just mathematically defined geographical coordinates – it is the dynamic basis of our interconnected world, which combines spatial, attribute and temporal components.

However, educational geospatial data has a number of features that allow it to be classified as educational elements (table 1).

Table 1. The main requirements for geospatial data that allow it to be classified as educational elements.

Criteria	General characteristics
Data quality	Data must be of high quality, up-to-date and reflect the current state of the studied objects or territories so that students can get a true picture of real geographical phenomena
Accessibility	Data should be easily accessible to teachers and students, preferably through open platforms or resources with minimal financial costs.
Clarity and structure	Information should be well organised, with clear descriptions and classification, so that students can easily interpret the data. Data should be accompanied by explanations or training materials to facilitate understanding
Compliance with educational goals	Data should correspond to curricula and course objectives, ensuring compliance with topics studied in geography lessons
Ability for interactive use	Data should support tools for interaction, analysis and visualisation (for example, through a GIS platform or special programs). This allows students to work with data directly, which promotes the development of practical skills
Security and confidentiality	If data contains personal or confidential information (e.g. user geodata), it is important that it is processed in accordance with confidentiality requirements to ensure student safety and avoid legal risks

The quality of geospatial data takes on special meaning due to the great practical importance of the results of geospatial analysis, the completeness and accuracy of which depends primarily on the quality of geospatial data. As a result, data whose quality is compromised can lead to erroneous conclusions drawn by students based on their analysis.

Parameters of geospatial data quality allow assessing how much a particular dataset meets certain criteria. They include data completeness, accuracy in determining the location of objects, and thematic and temporal accuracy.

Data completeness describes whether the data covers all the necessary objects and attributes for a specific analysis or application. It also indicates whether objects or attributes are missing. Location accuracy determines how accurately the coordinates of an object correspond to its actual position on Earth. Thematic accuracy refers to the correspondence of data to specific attributes or categories by which they are described. Temporal accuracy describes the relevance and accuracy of the time the data was collected. It is important that data is collected and updated at the right time, especially for dynamic processes such as weather phenomena or migration processes.

Determining the quality of geospatial data is quite a complex process since they lack physical characteristics that can be easily measured. Users use various methods to assess the quality of geospatial data [3, 21].

Availability of geospatial data is ensured by the ability to obtain a variety of data in the public domain. Today, much more GSD can only be obtained for a high price or subject to rather stringent terms of use. This significantly limits the possibility of their use in the educational process. Partial overcoming of this obstacle is possible with the help of open platforms, crowdsourcing and political initiatives regarding access to public data.

Clarity and structure of geospatial data is one of the main requirements for the effective use of GSD in education. This is due to the fact that unadapted geospatial data can be difficult for students to perceive and analyse. Therefore, information should be presented in an understandable form, using clear visualisations, legends and explanations. Complex geographical concepts should be adapted to the age and level of preparation of students. In addition, GSD should be organized into a logical structure that facilitates their search, analysis and interpretation. The use of classifications, categories and hierarchies helps students understand the relationships between different objects and phenomena.

Compliance of geospatial data with educational goals ensures, on the one hand, a connection with the curriculum and, on the other hand, compliance with educational objectives. GSD should be integrated into the curriculum and support the study of specific topics and sections. They should also help achieve specific educational goals, such as the formation of spatial thinking, the development of analytical skills, the ability to work with cartographic materials, understanding the relationships between objects and phenomena, etc.

The possibility of interactive use of geospatial data in the educational process allows not only to observe geospatial objects and phenomena but also to actively interact with them, explore, analyse and model. It provides feedback and active interaction of students with GSD and their visualisation in various formats.

Security and confidentiality of geospatial data are important aspects that must be taken into account when using this data in education. Ensuring security and confidentiality allows you to protect sensitive information and prevent its unauthorised access, use or disclosure. The use of GSD in education must necessarily be provided with the protection of personal data (for example, data on the location of students, their homes, schools, favourite places of rest, etc.), protection of confidential information (for example, data on the location of strategic objects, environmentally sensitive areas, archaeological monuments) and protection against unauthorised access.

Compliance with these requirements contributes to the effective use of geospatial data for educational purposes and helps the teacher provide interesting and relevant information that ensures the development of geoinformation competencies in students. But for the most part, the teacher must conduct preliminary preparation of the received GSD, which should include an analysis of their quality, the formation of structured and logical explanations, the selection of platforms for their demonstration, and more.

Thanks to the integration of geospatial data into the traditional process of teaching geography, the teacher gains a number of advantages, the main of which are:

1. Improving the visualisation of educational material. Geospatial data allows you to visualise information about the environment, which makes the material more visual and understandable for students. Interactive cartographic platforms and GIS allow students not only to view maps but also to explore reliefs, climatic conditions, and changes in ecosystems over different time periods and analyse the relationships between objects (figure 1).

2. Increasing student engagement. GSD provides an exciting way to study geography, engaging students in analysing real-world situations and data. They also allow for interactive projects and modelling of real situations, such as environmental research or urban planning,

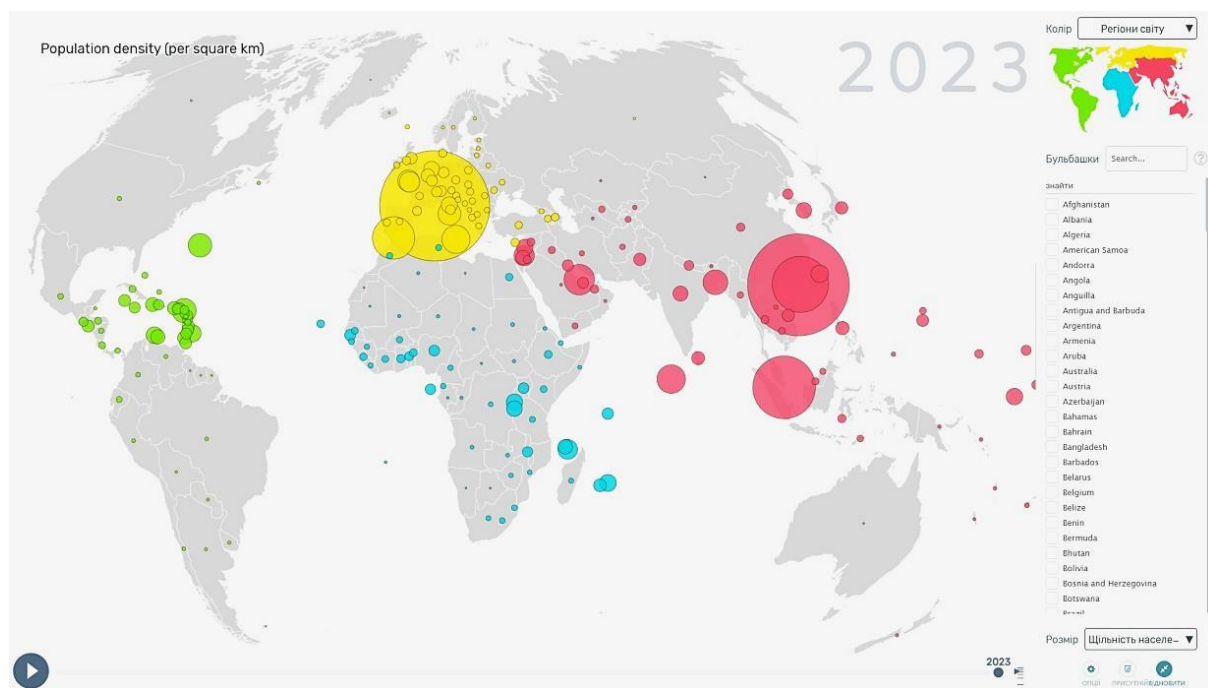


Figure 1. Map of population density in countries of the world in 2023 (according to <https://www.gapminder.org/tools>).

which enhances the sense of practical relevance of knowledge (figure 2).

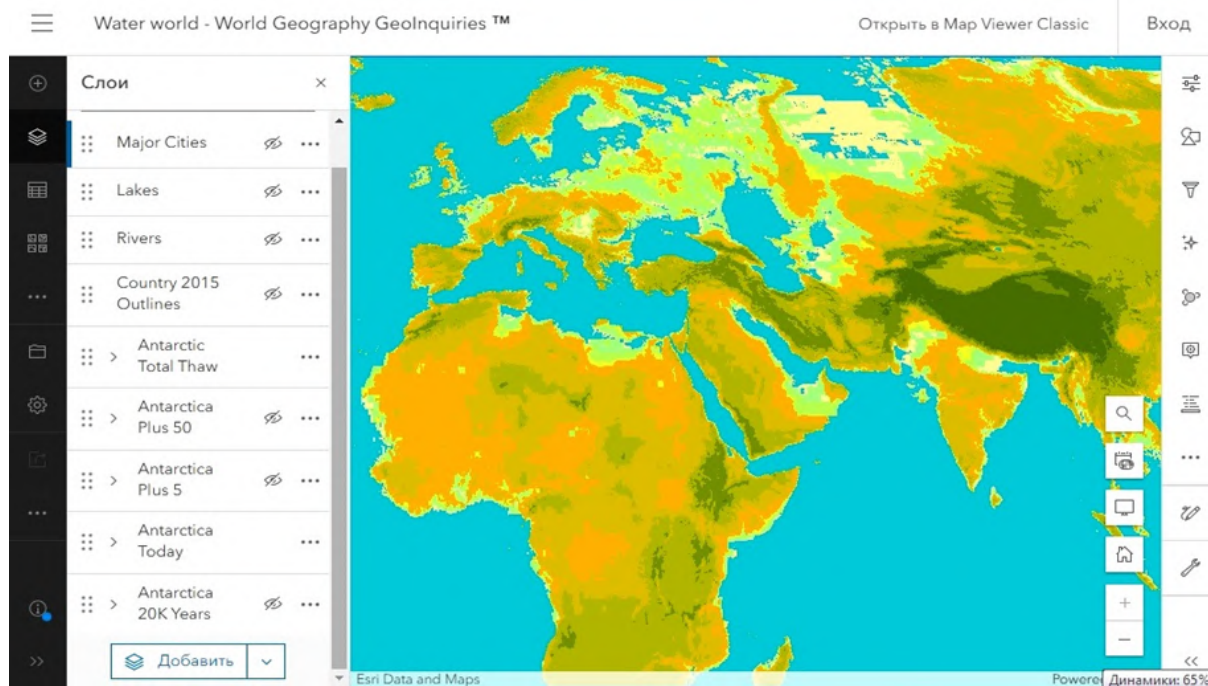


Figure 2. Map of the forecast of the Earth's relief after the melting of the Antarctic ice sheet (obtained using the GeoInquiries resource).

3. Individualisation of learning. The use of GSD in geography lessons allows you to customise tasks, focusing on each student's interests, level of preparation, and abilities. With access to tools such as GIS, students can choose their own research topics, allowing the learning process to become more flexible and adaptable to their needs.

4. Formation of skills in working with geoinformation technologies. GSD allows students to develop skills in working with geoinformation technologies, developing important skills in analysing and visualising spatial data. This process includes training in the basic principles of working with GIS [15].

5. Access to a large amount of information. GSD provides teachers with the opportunity to work with up-to-date and detailed cartographic, climatic, demographic and other data. Access to a large amount of geospatial data also contributes to the development of information analysis and processing skills, forms digital competencies, and stimulates students to participate in research activities. The teacher can also more effectively present complex educational material by integrating various dynamic maps, satellite images, digital terrain models, etc., into lessons.

However, it should be noted that despite the numerous advantages of using GSD in the educational process, educators face a number of problems that significantly hinder this process. Table 2 shows the main such problems and offers possible solutions.

One of the main problems hindering teachers from introducing geospatial data into the educational process is the uncertainty of pedagogical teaching methods using GSD, so let's consider it in more detail.

Problem-based learning is a powerful pedagogical method that encourages students to actively learn and independently solve problems, which, thanks to the use of geospatial data, becomes particularly relevant. The teacher creates a problematic situation related to a real geographical phenomenon or process. For example: *What will be the consequences for our planet after the melting of the Antarctic ice sheet?* Students put forward various hypotheses for solving the problem, using their previous knowledge and logic, and to test hypotheses, they turn to various sources of information, including visualisation of GSD on the *GeoInquiries* platform (figure 2).

The *project activity method* allows students not only to assimilate theoretical knowledge but also to apply it in practice, solving real problems based on GSD. The meaning of project activity is to involve students in creating their own projects, where they collect, process and analyse geospatial data. This can be the creation of digital maps, the modelling of natural phenomena, or the development of tourist routes. It is important that through practical work with geospatial data, students gain a deeper understanding of complex geographical processes and phenomena.

Gamification of the educational process makes the learning process more interesting and effective, turning it into an exciting adventure [2, 4]. Geographic games can help students visualise real-world data, understand spatial relationships, and apply geographic concepts interactively. This allows students not only to memorise facts but also to actively apply knowledge in practice, developing critical thinking, communication skills and the ability to work in a team. Games with an interactive map (for example, *Google Earth*), simulator games (*SimCity* or *Minecraft Education Edition*), role-playing and adventure games (*Ticket to Ride*, *Uncharted*) can be used.

As an example, let's cite the web game *GeoGuess*, which transports players to different parts of the world, to random places (from busy city streets to remote rural areas), as depicted in Street View from *Google Maps*. The goal of the game is to determine the location using only visible geographical clues (figure 3).

The program assigns the player a score depending on how far the player's guess was from the real place.

Independent work is one of the most effective pedagogical methods for integrating GSD into the school geography course since, thanks to it, students develop skills in analysing and working

Table 2. The main challenges of integrating geospatial data into the educational process and proposed possible solutions.

№	Problem name	General characteristics	Possible solutions
1	Limited access to educationally oriented geospatial data	A large amount of publicly available geospatial data does not meet the demand for data adapted to the school curriculum. Many available data are created for professional use and do not take into account the level of knowledge of schoolchildren.	- Teachers who have a sufficient level of knowledge in the field of geoinformation technologies can independently adapt data in the public domain to the topics of the school curriculum; - Using geodata provided by individual commercial organisations, they are aimed at supporting education in the field of geoinformation technologies; - Using authentic GSD
2	Technical limitations	Lack of necessary hardware (powerful computers and peripherals), specialised software and high-speed Internet in schools	Use of cloud technologies that are less demanding on computer power, as well as free open source software, or cloud GIS platforms that reduce hardware requirements by performing online analysis
3	Limited number of hours in the school geography course	In most schools of the world, the weekly number of hours in the basic geography course does not exceed 2-3 hours. At the same time, existing curricula do not provide for working with geospatial data	- Use project work where students independently collect and analyse geospatial data to solve specific problems; - Integrate geospatial data into lessons in the form of short (up to 10-15 minutes) tasks that correspond to the topic of the school curriculum
4	Uncertainty of pedagogical teaching methods using GSD	The issues of pedagogical methods and technologies for using geospatial information in the process of teaching geography remain insufficiently studied and developed	Use the following methods and technologies: problem-based learning, project activities, gaming technologies, independent work

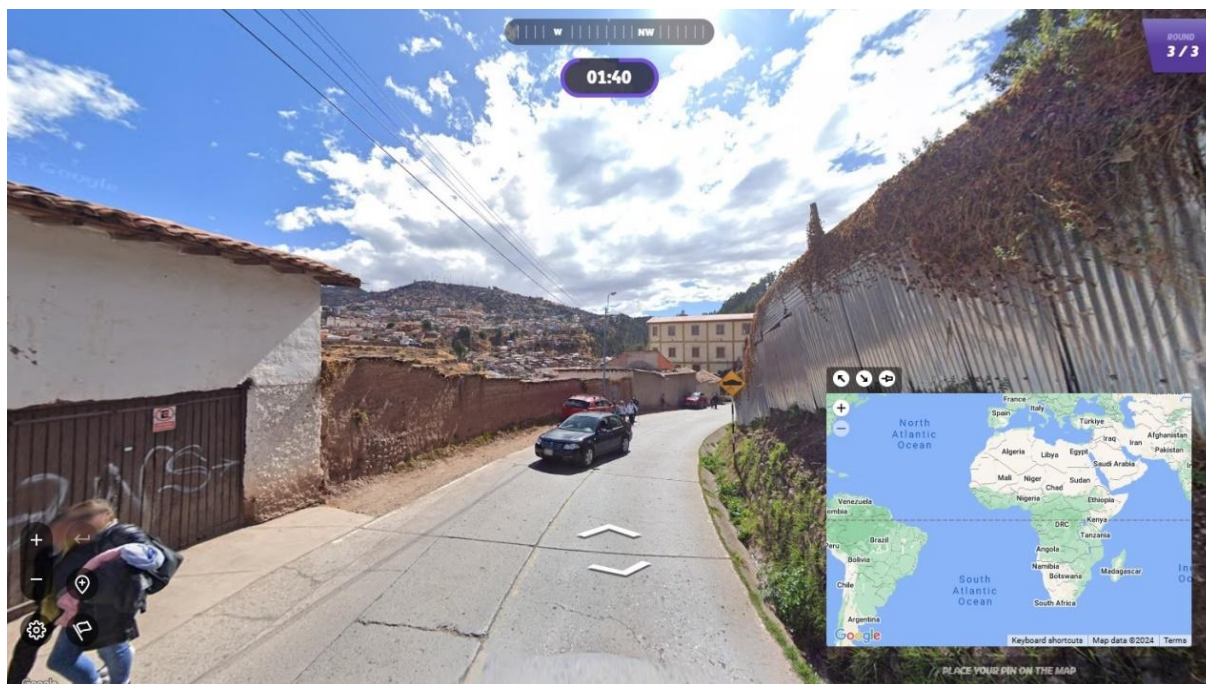


Figure 3. Working window of the GeoGuessr geogame (according to <https://www.geoguessr.com/free/>).

with information and also learn to independently research and solve tasks, which significantly increases their geoinformation competence. The teacher chooses methods of independent work depending on the level of preparation of students: from field work to individual projects.

For example, using geospatial data from the *EO Browser* platform in the form of satellite images from the *Sentinel-5P* satellite, which specialises in monitoring the atmosphere (figure 4), students can study the level of NO_2 air pollution in large cities of Ukraine and the impact of this on the environment.

With the help of these images, students have the opportunity to analyse the results obtained and answer the questions:

- are NO_2 concentration levels elevated in certain cities?
- how do they change throughout the year?
- what are the possible sources of pollution (road transport, industry, etc.) and the potential impact on the population and the environment.

Upon completion of the research, students present the study's results in a report or presentation with visualisations and conclusions. Information can be presented using graphs, satellite images, thematic maps, and comparative charts.

It should be understood that to use geospatial data in the educational process, and the teacher can use a number of tools that make learning interactive and close to modern research methods.

Equally important is the assessment of students' learning achievements in the use of geospatial data, which should be systematic, comprehensive, and cover not only the acquisition of theoretical knowledge but also the development of practical skills, research skills, and the ability to collaborate. Traditional assessment methods can be supplemented and modified to take into account the specifics of working with geographic information technologies.

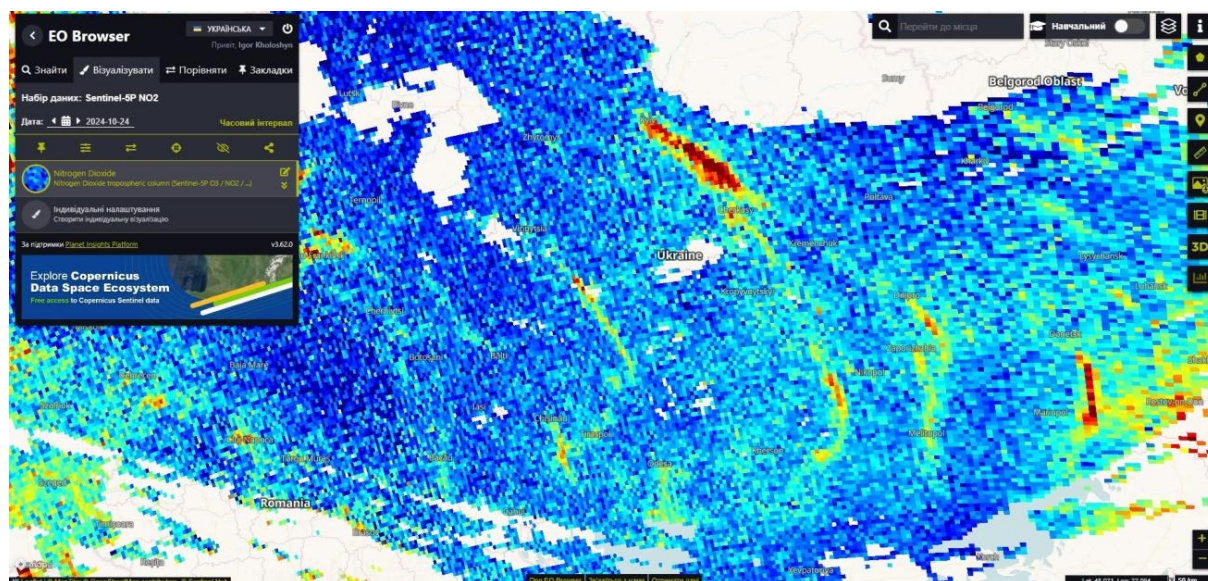


Figure 4. Satellite image of NO₂ concentration in the atmosphere of Ukraine (Sentinel-5P satellite, date 24.10.24, source EO Browser).

Today, there is a wide selection of freely available tools that provide opportunities for introducing geospatial data into the school geography curriculum.

First, there are the geographic information systems *QGIS* and *ArcGIS Online*. These platforms provide tools for creating maps, analysing data, modelling and visualising spatial phenomena.

But, unfortunately, there are not many teachers in schools in Ukraine and in other countries of the world who are able to work with these programs. Therefore, nowadays, various educational platforms are more popular tools. These are, for example, *Gapminder Tools*, *MapMaker Interactive*, *GeoInquiries* and others. So, *MapMaker Interactive* (from *National Geographic*) offers tools for creating maps with different themes and layers (for example, physical-geographical, demographic or socio-economic indicators). Students have the opportunity to explore multi-thematic world maps (figure 5), which allows them to study the physical-geographical and social features of different regions visually.

Mobile apps for collecting field data, such as *Survey123* or *Collector for ArcGIS*, cannot be ignored. These systems allow students to collect and update data in the field using mobile phones, which is valuable for studying local ecosystems and geographic processes.

It should be noted that most of the proposed educational tools, on the one hand, act as sources of geospatial information and, on the other hand, as platforms for their processing and analysis (table 3). For example, online resources for working with satellite images *EO Browser* and *NASA Worldview* provide access to real satellite data and then explore it in real-time, which is especially useful for analysing environmental changes.

Each of these tools allows users to analyse geospatial data and develop practical skills that are important for understanding spatial information and its application in real research.

Analysing the future development of the use of GSD in education, it should be noted that modern research generates more and more data, which raises the question of effective storage, management and processing of such data, which necessitates the integration of new technologies and primarily concerns artificial intelligence (AI). AI provides new opportunities for process automation, analysis of large amounts of data and improved accuracy of interpretation.

As a result, a new direction of research has been formed today – geospatial artificial



Figure 5. MapMaker Interactive platform window with layers of geospatial data (according to <https://www.arcgis.com/apps/instant/atlas/index.html?appid=0cd1cdee853c413a84bfe4b9a6931f0d>).

intelligence (GeoAI), which is an integration of artificial intelligence with GIS and geospatial data (figure 6), the purpose of which is to solve various geospatial problems better.

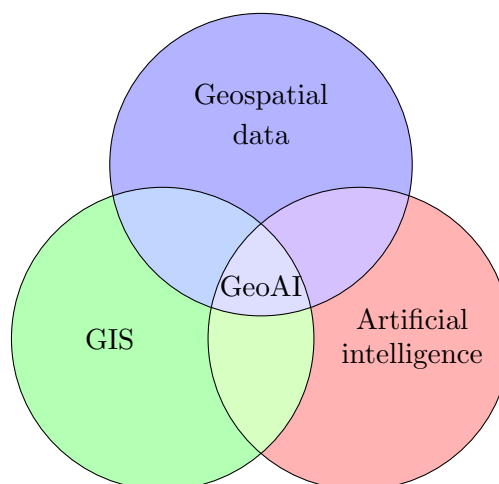


Figure 6. The main components of geospatial artificial intelligence.

An important aspect of GeoAI is the application of traditional artificial intelligence methods in obtaining geospatial data by extracting, classifying and detecting information from structured and unstructured data. These data include tabular data, remote sensing data and even textual data [7].

Table 3. Geo-platforms – sources of geospatial data and a tool for processing them

Platform name and URL	General characteristics of the resource
EO Browser https://apps.sentinel-hub.com/eo-browser	Cloud platform with medium and low-resolution satellite imagery with cartographic reference and tools for their processing
Gapminder www.gapminder.org/tools	Web platform that displays statistical geospatial data for most countries of the world and many subnational regions in the form of maps
Tableau Public https://public.tableau.com/	Interactive platform for visualising geospatial data, in particular socio-economic indicators. Allows you to create graphs, charts, maps and other tools for analysing data from various sources.
Google Data Studio https://datastudio.google.com/overview	Geo-platform that allows you to analyse and visualise geospatial data of various socio-economic indicators.
Google Earth https://www.google.com/intl/ua/earth	Virtual globe with satellite images of the entire earth's surface. It has common functionality: multi-temporal images, cartometric calculations, creation of your own tags and others
GeoInquiries https://esriurl.com/GeoInquiryStoryMap	Educational geospatial platform that provides the ability to build your own interactive maps of various themes
GeoGuess https://www.geoguessr.com/free/	Geo-platform game, the purpose of which is to determine the location using only visible geographical clues
MapMaker Interactive https://education.nationalgeographic.org/	Educational geospatial platform that allows you to analyse and visualise various sets of geospatial data (relief, climate, biodiversity, etc.)

GeoAI is changing the speed of analysis of complex geospatial datasets, helping to solve the Earth's most pressing problems. It reveals and helps to perceive complex patterns and connections in diverse data, the amount of which continues to increase significantly.

The main directions for using GeoAI in education are:

- *Automated collection of geospatial data.* GeoAI algorithms allow for automatic identification of objects in satellite and aerial images using computer vision and obtaining information about the state of territories with high speed and accuracy, minimizing human error.
- *Processing and interpretation of large volumes of geospatial data in real time.* The use of GeoAI ensures the optimisation of the processes of collecting, processing and analysing large volumes of geospatial information, which allows for obtaining operational and detailed analytical data. So, in the rapid development of technologies, sources such as GPS devices, mobile applications or sensors on vehicles provide huge amounts of geospatial data in real-time.
- *Spatial predictive analytics.* GeoAI allows predicting future changes in space based on the analysis of large volumes of historical and current GSD. For example, the *Google DeepMind* artificial intelligence model called *GraphCast* was trained on nearly 40 years of historical data, and this allows for a 10-day forecast with a six-hour interval for locations around the globe in less than a minute (figure 7). At the same time, GraphCast turned out to be 10 per cent more accurate than the traditional European weather forecast model.

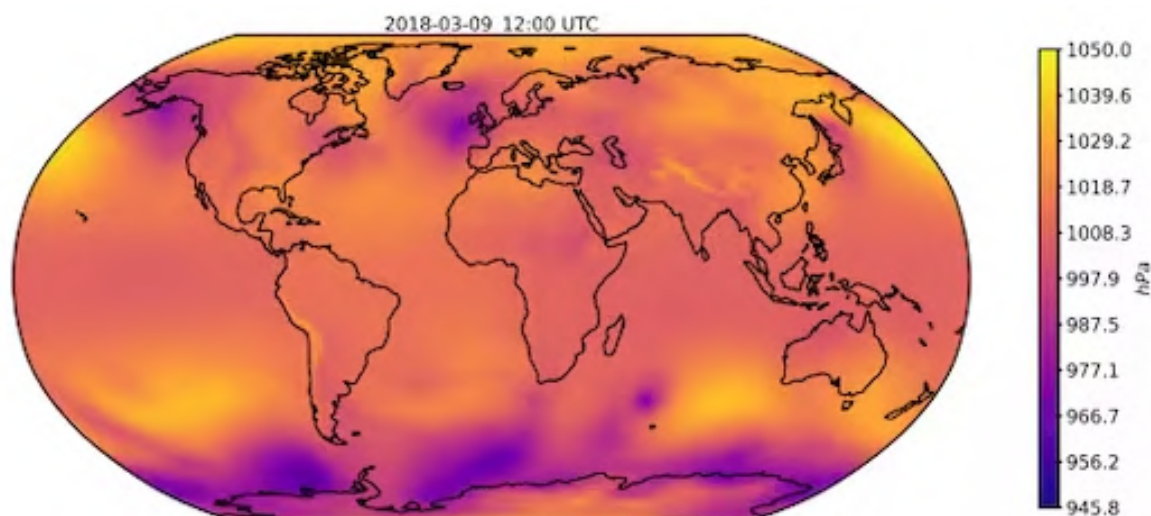


Figure 7. GraphCast atmospheric pressure forecast (according to <https://www.washingtonpost.com/weather/2023/11/14/weather-forecasting-artificial-intelligence-google/>).

It should be noted that this direction in the educational use of GSD is in the process of formation, and this requires separate research.

3. Conclusion

The conducted studies of the peculiarities of pedagogical methods and technologies for the use of geospatial data in the school geography course allow us to come to the following conclusions:

1. Geospatial data plays an important role in the formation and development of analytical and geospatial thinking, ensuring the practical application of knowledge and interactivity of learning.
2. The use of geospatial data in the school geography course provides:
 - development of spatial imagination;
 - improving the visualisation of educational material;
 - increasing student engagement;
 - individualisation of learning;
 - formation of skills in working with geoinformation technologies;
 - access to a large amount of information.
3. The use of various methods and technologies in integrating geospatial data helps to make the learning process exciting and effective, contributing to the development of important skills in students for critical analysis and working with geospatial information.

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AI tools and their application for developing soft skills of computer science students: the perspectives of IT specialists and university teachers

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Abstract. An attempt to understand whether artificial intelligence (AI) technology can help enhance the development of soft skills of the graduates of the faculties of information technologies and today's computer science (CS) students is the aim of the paper. The descriptive method and expert survey method were applied to this study. The study found that nowadays, there are AI tools for solving professional tasks in the IT industry that require the use of developed soft skills. Among the most widely used tools are AI Chats, AI-powered apps for improving the content of texts and text correction, platforms for efficient work with the involvement of AI technology. Two surveys were conducted as a part of the research: among IT specialists, and among university teachers who teach CS students. Resulting from the performed study it was determined that the more experienced the survey participants were, the more often they were satisfied with the results of using AI in their professional activities, agreed that AI is effective for work assignments that require a soft skill to resolve them effectively, were more likely to consider the use of AI in the professional training of IT majors appropriate.

1. Introduction

The technical (hard) skills of those who work in information technology (IT) are undoubtedly fundamental. However, as scientists stated, in the past decade, “soft” skills have been more frequently required than “hard” skills [1]. In the World Economic Forum’s “Future of Jobs 2023” report, cognitive skills topped the list of those skills that were considered the most important skills to workers in 2023 (figure 1).

Creative and analytical skills rank first in the list of skills (figure 2), the importance of which is projected to increase for employees by 72% during the next five years.



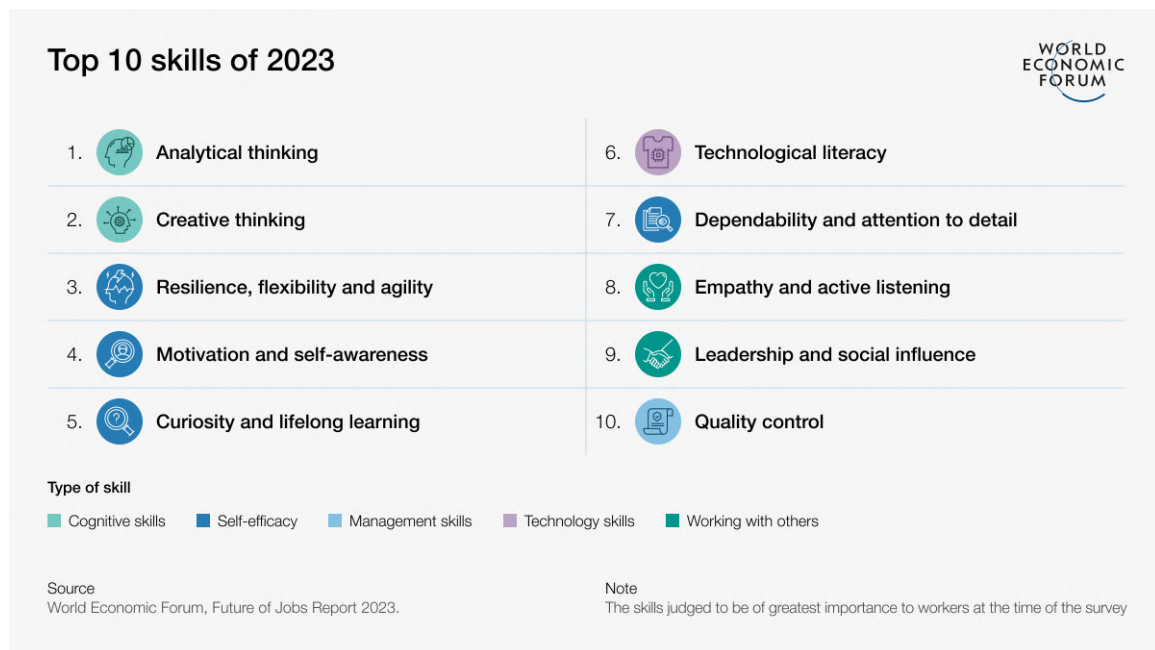


Figure 1. Top skills of 2023 according to the World Economic Forum’s “Future of Jobs 2023” report [2].

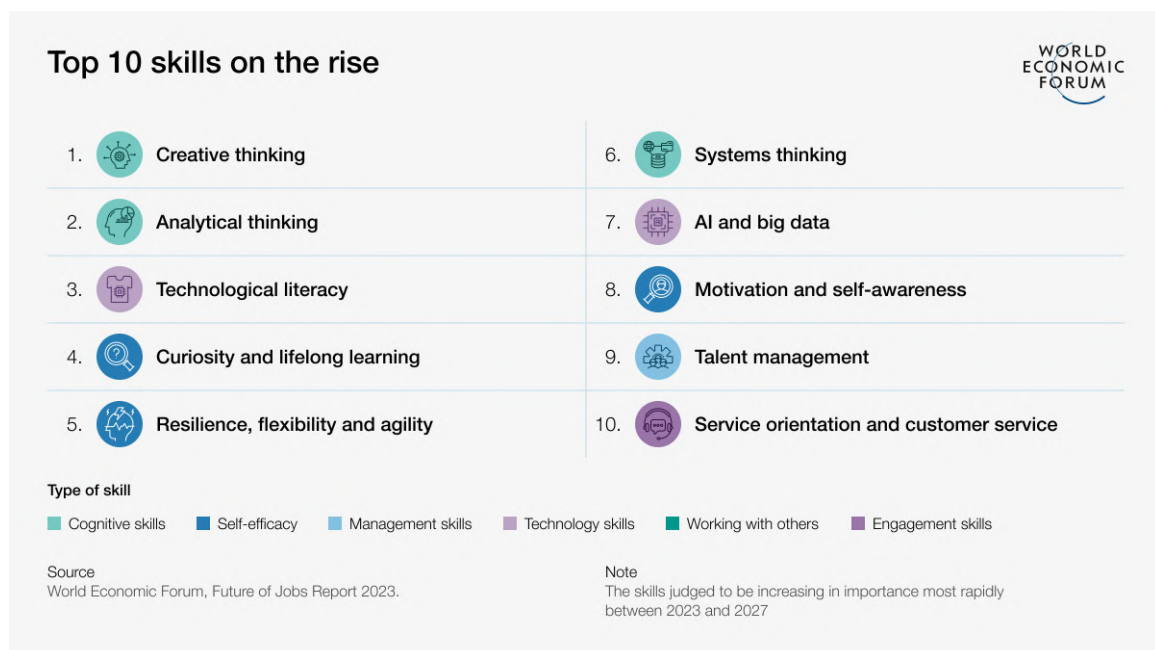


Figure 2. Top skills on the rise according to the World Economic Forum’s “Future of Jobs 2023” report [2]

So, employers in the IT sphere also need not only technical knowledge from workers who work for them but also professional skills that would allow the firms to achieve more and better results. Today’s work requires IT workers not only technical knowledge and skills in the IT field. They must also have the skills at the intersection of disciplines.

Currently, AI is at the forefront of technology, research, and education [3–12]. In this regard, the following question logically arose: Why not use AI technologies, particularly AI tools, to work on the development of soft skills (SS) of today's computer science (CS) students?

The current research **aims** to answer the above-stated question. For this, the research questions (RQ), as prompts, are determined to discover the essence of the current study's aim:

- RQ1. What AI tools are available today and applicable to decide work tasks in the IT sphere that require strong soft skills to resolve them?
- RQ2. What is the opinion of experienced specialists in information technology and university teachers regarding using AI tools to decide professional IT-related tasks, the implementation of which requires strong soft skills?
- RQ3. Is using AI tools for soft skills development appropriate while training IT majors?

2. Literature review

Today, skills such as being a team player, self-motivation, verbal communication, problem-solving, and being proactive are often among the highest-ranking skills for employment. In the same way, the ability of employees to work well independently, in a proactive and self-motivating manner, and work effectively in a team is valued [13]. When interviewing CS graduates, the participants valued professional SS above technical hard skills [14]. It is believed that 84% of the workforce insists job candidates must demonstrate SS [15].

Moreover, based on their research [16] scientists noted that in such a rapidly changing technological era, experienced professionals value soft skills, particularly efficient communication skills, rather than hard skills. It should also be noted that they value soft skills with equal importance or even higher than hard skills. This study also showed that the soft skills gaps in the non-computing curriculum are much more significant than the gaps in computing disciplines. At the same time, the formation and development of soft skills enable the students not only to meet the requirements of the labor market but also to develop professional skills (hard skills) more successfully [17].

So that is why there is a pressing need to upgrade and renovate training programs for IT specialties to meet better the expectations of the leading figures of the IT industry regarding the training of a new generation of IT majors, resulting in the improvement of their soft skills. Scientists offered several methods, technologies, and approaches to forming and developing soft skills in IT majors. In particular, Milczarski et al. [18] involve multinational and interdisciplinary teams of students in teamwork for game development. In their view, this teamwork contributes to the communication and collaboration of IT students from diverse backgrounds. Paredes-Velasco et al. [19] proposed a pedagogical approach based on interdisciplinary practice and realistic problems to cultivate, enhance, or deepen the teamwork skills of CS students. In scientists' opinion, a project-based learning technology is a good way to develop the soft skills of CS bachelor students [17]. Abernethy and Treu [20], with a like-minded team of researchers, worked under the IT curriculum for undergraduate IT programs. Moreover, Abernethy and Treu [20] proposed one of the most interesting approaches appropriate for developing communicative skills in authentic surroundings: to use projects oriented to the customers, which are the training courses in which real customers take part. By applying this approach, students gradually build up their soft skills, as acquiring and applying this approach requires students' competence in interpersonal interaction and the use of communication skills. At the same time, applying this approach allows for developing or improving IT majors' communication skills in training, simultaneously with applying well-developed hard skills in the design, implementation, coding, and testing of IT products. No less interesting is the use of the design thinking methodology, which promotes the production of creative and innovative software solutions required for software

development by means of simulating scenarios of real projects that require innovative decisions [21].

These studies have received positive results. Engaging students to work in multinational and interdisciplinary teams for game development allows IT educators to give students an idea of how modern IT companies work and contributes to the development of effective practical project management skills. As a result of applying an interdisciplinary approach, students are gradually improving their ability to work and collaborate in a team. The method of using project-based learning technology also contributes to progressively increasing the level of soft skills formation for CS bachelors. Namely, it is about forming personal effectiveness, communication, managerial, strategic, and information management skills. Applying a project development approach involving real customers allows students to practice communication skills, bridging the gap between theory and practice. Implementation of the Design Thinking methodology promotes the development of communication skills. Also, it contributes to forming problem-solving skills, increasing creativity, supporting effective practical teamwork ability, and diversifying and critical thinking. Although these methods have proven effective, traditional curricula (training programs) pay much more attention to developing technical hard skills over soft skills, potentially leaving shortcomings in the professional training of IT majors. It remains, and constantly increasing, a noticeable gap between the soft skills that employers seek and require and those skills, mainly well-developed hard skills, that IT students usually obtain after graduation. This situation shows the ratio between academic training and IT industry needs [22].

It is important to remember that the world is moving forward, and new technologies (AI tools) can be applied so that IT professionals with low soft skills can demonstrate higher-level skills and be more productive in their work. AI is a trend in modern society and the point of interest for both students and teachers. Integrating AI into developing the soft skills of IT students is increasingly recognized as essential for students' future professional activity and successful fulfilment of working tasks. Recent scientific publications emphasize the potential of applying AI technology to improve the soft skills of IT majors [5–7]. Recent research confirms the positive cases of applying AI to develop soft skills. At the same time, the necessity to deeply study the ways of using and evaluating the effectiveness of AI in training is still relevant, and it exists [8]. Let us note that scientists [9] emphasize that to bridge the skills gap between industry demands and technical proficiency, academic institutions should incorporate creative teaching approaches that prioritize soft skills like problem-solving, teamwork, and communication.

Thus, the literature analysis has led us to believe that a strong soft skill set to work effectively in the IT industry is a requisite facet of the labor market requirements. Employers increasingly value teamwork, communication, problem-solving, etc. However, soft skills development at IT faculties is often given insufficient attention. To solve this issue, researchers propose various methods for developing soft skills in IT education, including project-based learning, interdisciplinary teamwork, and the integration of AI tools, while highlighting the need for academic institutions to adapt their curricula to better align with IT industry demands. So, the literature analysis confirms the relevance of the research questions posed.

3. Theoretical background

Soft skills and AI – are essential in the modern business reality in general and the IT industry in particular. Scientists claim that while AI excels at automating technical tasks and routine activity, the key to productive and profitable work – is a thriving, successful, and prosperous workforce and a unique human ability to foster soft skills for their intended purpose [23]. Are soft skills essential for IT professionals? It is possible to assert that soft skills are critical to long-term cooperation and teamwork. The terms that are used for characterizing soft skills vary in different sources.

Technical and professional skills are defined more or less clearly [14]. Some notions are given

below:

- (i) Technical skills involve discipline-specific knowledge [24], particularly engineering or computing skills;
- (ii) Professional skills include interpersonal and intrapersonal skills, which are, in principle, independent knowledge. They consider everything from lifelong learning to the understanding of ethics and professionalism [25] and are also known as generic competencies [26], transversal, key, professional, soft, and 21st-century skills [27].

Hard skills can be recognized as technical skills acquired due to an academic qualification. Conversely, soft skills are personal life skills and are more subjective [28]. However, there are variations of these definitions, as can be seen in figure 3.

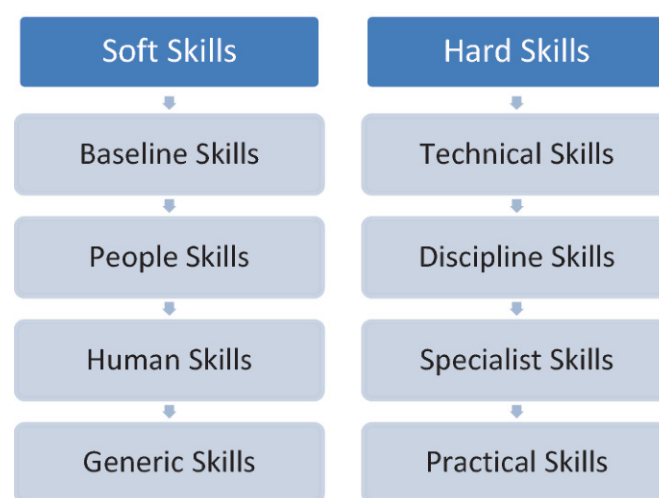


Figure 3. Baseline skills – scaffolding soft skills development within the curriculum [28].

The question of developing soft skills is common, but it remains relevant for today's educational process at the university level. Soft skills, generally characterized as non-technical skills that allow individuals to interact effectively and harmoniously with others, are essential to companies and can impact culture, perspectives, administration and supervision, mindsets, and behaviors. Soft skills fall into the categories [29]: advanced communication and negotiation skills, interpersonal skills and empathy, leadership and management skills, entrepreneurship and initiative-taking, adaptability and continuous learning skills, and teaching and training skills.

As defined in Cambridge Advanced Learner's Dictionary & Thesaurus, the notion of "soft skills" refers to an ability that does not depend on the knowledge needed for one particular job but on, for example, being able to work well in a team or communicate well with people [30]. As stated in the document "Criteria for Accrediting Computing Programs by Accreditation Board for Engineering and Technology (ABET)" [31], considering all existing student outcomes that enable graduates to attain a mastery of a Computing field, one can distinguish the following soft skills: (1) communicate effectively in a variety of professional contexts; (2) recognize professional responsibilities and make informed judgments in computing practice based on legal and ethical principles; (3) function effectively as a member and leader of a team engaged in activities appropriate to the program's discipline.

Let's consider the data from the documents "Criteria for Accrediting Engineering Program by ABET" [32]. We obtain a more exhaustive list of results for students who are studying Engineering Programs. This list includes the following range of skills: (1) an ability to

communicate effectively with a range of audiences; (2) an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts; (3) an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives; (4) an ability to acquire and apply new knowledge.

So, as of today, there are no established views on the list of soft skills essential for CS students. However, many scientists, as well as document creators, such as authors of the document “The Criteria for Accrediting Engineering and Computing Programs”, emphasize the importance of specific skills. In particular, scientists highlight the importance of soft skills, such as **communication skills**, for clear and effective interaction within teams and with stakeholders [9, 33, 34]; **teamwork and cooperation** that vital for effective practical work in team projects and the real world [9, 34, 35] and encourage the development of interpersonal skills and the ability to work harmoniously with others [36, 37]; **problem-solving skills** that necessary for identifying, analyzing and solving complex issues [9, 33, 34] and for increasing critical thinking and the ability to methodically approach problems [35]; **interpersonal skills** that include active listening, the ability to build relationships [38] and creating a positive work environment and effective collaboration [36]. In researchers’ view, no less required are **time management and organizational skills** that are essential for managing workloads, meeting deadlines, and prioritizing tasks [37] and help maintain productivity and efficiency in a rapidly evolving environment [28]; **self-management skills** that are important for continuous personal and professional growth [38]; **leadership skills** that assist in decision making by taking responsibility [33, 36], encourages initiative and the ability to influence and motivate others; **creativity** that encourages thinking outside the box and developing new solutions and essential for adapting to new challenges and driving technological advancements [35].

Thus, based on the analysis of research relating to the development or enhancement of soft skills in the professional training of CS students (Introduction Chapter of the current research) and the above list of soft skills for Engineering and Computing Programs by ABET, we have identified a list of soft skills for our study.

4. Methodology

This study employed the descriptive method [39] and the expert survey method [40, 41]. Exploiting the descriptive method made it possible to analyze scientific papers and internet material to determine the appropriate AI tools for performing professional tasks requiring soft skills. The expert surveys were used to answer the RQ2 and RQ3. The target survey group consisted of IT specialists and university teachers (IT educators) who teach CS students. Applying a qualitative research method made it possible to process collected data, analyze this data, and answer research questions. The point of concern mirrored in the survey was the use of AI tools to complete professional tasks involving students’ soft communication skills ability. It was also important to consider the feasibility of using AI tools in the professional training of future IT specialists. All survey participants were briefed on the study and consented to participate. The survey used the Google Forms tool with privacy settings.

4.1. Methods for analyzing the research to select existing AI tools for performing professional tasks related to soft skills

Aiming to analyse existing AI tools that help perform professional tasks that require applying well-developed soft skills, we searched for scientific publications in the platform Scispace. We asked two questions on this platform:

(Q1/Scispace) Are there any scientific articles that suggest the use of AI in the process of developing soft skills for students who major in CS?

(Q2/Scispace) How does using AI tools contribute to developing the soft skills of students majoring in CS?

We received a list of 100 scientific articles for every stated question – Q1/Scispace & Q2/Scispace – mentioned above. Scientific papers were evaluated for their correspondence to the inclusion and exclusion criteria table 1.

Table 1. Inclusion and exclusion criteria.

Inclusion	Exclusion
Peer-reviewed scientific publications involving higher IT education	Scientific works not related to higher IT education
Include topics of forming or developing SS in IT students with the help of AI tools	Not include topics of forming or developing SS in IT students with the help of AI tools
Published between 2022 – 2024	Published before 2022, published in a language other than English
Published in English	Closed access
Open access	Duplicates

After employing inclusion and exclusion criteria, eight studies were included in the analysis (figure 4). We also searched in the Scopus AI. Among the available functions of this tool (a Summary, an Expanded summary, a Concept map, Topic experts, “Go deeper”, Emerging themes), we used Summary and Expanded summary to search for relevant scientific sources related to the topic and issues of artificial intelligence tools that contribute to the development of soft skills in CS students.

We received 16 scientific articles in response to the question we had posed in Scopus AI (Is using AI tools for soft skills development appropriate while training IT majors? (Q3/ Scopus AI)). Then, we checked the articles for compliance with the inclusion and exclusion criteria. Two studies were included in the analysis. Thus, 10 articles were included in the analysis (figure 4).

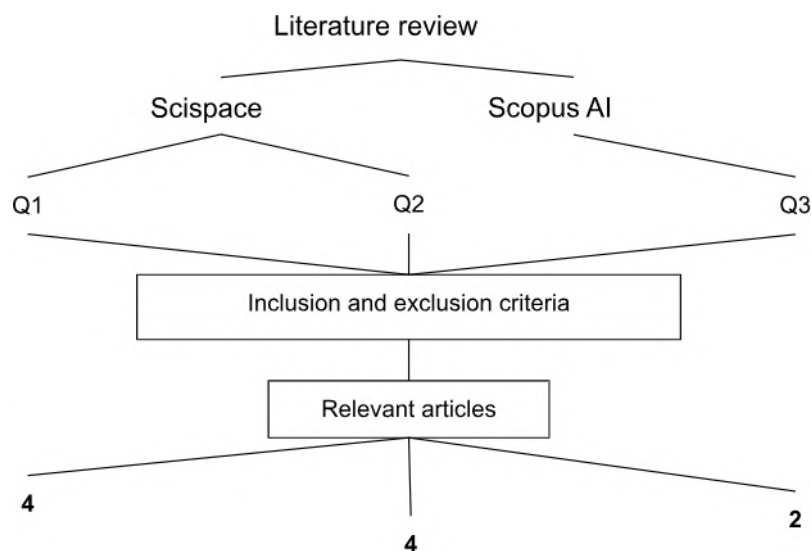


Figure 4. The results of searching for scientific publications in Scispace and Scopus AI.

We were trying to find the answer to the first question (RQ1: What AI tools are available today and applicable to decide professional tasks in the IT sphere that require applying well-developed soft skills) by analyzing scientific publications. However, the search results needed to be comprehensively studied. For this reason, we searched for information on Internet resources, keeping in mind the soft skills listed and characterized in the “Theoretical background” section of this research. We exploited Google Search to find answers to the following questions:

- (1) Which AI tools are used for communication and provide clear and effective communicative interaction between the team members and stakeholders?
- (2) Which AI tools are used in teamwork and collaboration in IT companies and the IT sphere in general?
- (3) Which AI tools are used for problem-solving in the IT industry?
- (4) Which AI tools are used to foster interpersonal communication among specialists in information technology?
- (5) Which AI tools are used for time management and organizational processes in IT companies?
- (6) Which AI tools are used for the self-management of specialists in information technology?
- (7) Which AI tools are used by the IT industry’s leaders (e.g., the CEO or executive director) to perform tasks?
- (8) Which AI tools are used to find creative solutions and new ideas for the IT industry?

The results of the Internet materials analysis are presented in the section 5.1.

4.2. Expert survey method

The survey among specialists in information technology and university teachers who teach CS students was conducted in November and December 2024. Collecting and processing the opinions was carried out online with the Google Forms application. Private data were not collected. Two surveys were proposed. The first survey was proposed for the IT specialists. The second survey was proposed for IT educators.

Survey one for IT specialists (Appendix A) consisted of seventeen questions. These questions were presented in five sections: (1) general information (gender identity, experience of working in the IT sphere, degree in education); (2) information about the company where the expert – a specialist in IT technology – works; (3) experience in using AI (questions related to the use of AI for working in the IT sphere, the use of AI in the training of CS students, the purpose of using AI in training of CS students); (4) experts’ opinion on the use of AI tools in the professional training of CS students; (5) the purpose of the use of AI in the preparation of the CS students and own professional activities.

Survey two consisted of nineteen questions and was offered to university teachers who teach CS students (Appendix B). These survey questions were presented in six sections: (1) general information (gender identity, the experience of working with CS students); (2) information about the university where the teacher works; (3) experience of using AI in everyday professional practice; (4) opinion on the use of AI in professional training of CS students; (5) the purpose of the use of AI in the training process, and their work. The results of the surveys and their analysis are presented in the section 5.2.

5. Results

5.1. AI tools and AI technology that are applicable for developing, improving and applying soft skills

Considering the results of a search of the scientific publications in Scispace and Scopus AI we have analyzed 10 documents that hypothetically could shed light on the existing AI tools that

are applicable for developing, improving, and applying soft skills in the professional IT sphere. The results of the conducted analysis are presented in table 2.

Table 2. AI tools and technology for applying soft skills in the professional IT sphere.

Types of soft skills	AI technology / AI tools	Source
Communication skills Collaboration skills	Fuzzy rules and machine learning techniques	[42]
Communication, critical thinking, creativity, leadership, adaptability, and emotional intelligence	AI-based personalized learning platforms	[43]
Communication skills, critical thinking, team skills, empathy in communication, etc.	ChatGPT, Grammarly, Google Bard (Gemini), Notion, Midjourney	[8]
Communication, negotiation, problem-solving, finding a common language with colleagues and clients, public speaking, and intercultural	Microsoft Copilot, AI tools for public speaking (Yoodli, Verble, Gabble, Virtual Orator, Orai)	[5]
Communication skills (for reducing social anxiety)	Cross-platform application utilizing AI	[44]
Critical thinking, problem-solving abilities	GenAI-Based virtual assistants	[45]
Communication skills, collaboration skills, creativity skills, critical thinking skills, problem-solving skills	Intelligent tutoring systems, AI chatbots, automated assessment systems, dashboards	[46]
Critical thinking, problem-solving	ChatGPT	[47]
Collaboration, communication	Intelligent tutoring systems, adaptive learning platforms, AI-powered VR and AR, virtual assistants, automated grading systems, natural language processing, data and learning analytics and chatbots	[48]

Considering the results of a search of Internet sources related to the use of AI tools for developing, improving, and then applying soft skills in the IT sphere, we have compiled a list of AI tools applicable to completing professional tasks in the IT industry. The results of the conducted analysis are presented in table 3.

So, based on the search for scientific publications in Scispace and Scopus AI, we found out which AI tools, according to scientists, can be used by IT students to perform future professional tasks related to their use of soft skills. This list has been expanded by analyzing Internet sources. To harmonize theory and practice, we surveyed specialists in IT and university teachers who teach CS students, and the results and analysis are given in the following subsection.

5.2. Survey analysis and figuring the correlation between the experience and the extent of use of AI by specialists in IT and university teachers who teach CS students

The survey was aimed at 1) gathering and analyzing the points of view of specialists in IT and university teachers who teach CS students on the use of AI tools for carrying out tasks,

Table 3. AI tools for performing professional tasks in the IT-sphere for which SS are essential.

Soft skills	AI tools
communication skills	<i>Microsoft Teams, Slack, and Zoom</i> with AI are used to summarise conversations, prepare transcripts, etc. [49]; <i>Jasper.ai</i> – to create high-quality written content using AI; <i>ChatGPT</i> – to conduct natural language processing and communication; <i>Grammarly</i> – to improve the quality of writing following grammar and style suggestions [50].
teamwork and collaboration	<i>TARA</i> is used to optimize the efficiency and performance of teams based on identifying spheres that have to be improved and providing personalized resources to help them achieve their goals; <i>Notion</i> – to automate repetitive tasks and provide advanced productivity tools, and <i>Taskade</i> – to optimize project management processes and productivity, automate repetitive tasks and provide tools for collaboration [51].
problem-solving skills	<i>Fordi AI</i> is used to answer work-related questions; it also helps one find solutions for everyday tasks and offers ideas. Correspondently, <i>ShotSolve</i> – to decide the issue immediately by taking screenshots. <i>Texti</i> – to supports problem-solving and collecting information by seeing a real-time preview.
interpersonal skills	<i>Mindreader</i> enhances communication by analyzing linguistics and physiology, providing personalized insights and recommendations for effective communication.
time management and organizational skills	<i>Microsoft 365 Copilot</i> is used to provide each employee with a Copilot as a personal assistant [52]. <i>PPM Express</i> – to perform project portfolio management, project planning, execution, and monitoring; <i>Asana</i> – to do work management, combining task management functions, project planning, and team collaboration; <i>Monday.com</i> – to conduct team communication and provide a visual platform for the teams to collaborate on projects and tasks [53].
self-management skills	<i>Clara</i> is helpful in scheduling the meetings, communicating with the participants, and adding details to the calendar; <i>ClickUp</i> – in workplace productivity, time tracking, and prioritizing tasks based on urgency and importance. <i>Reclaim</i> – in calendar management and time tracking [54].
leadership skills	<i>Trello</i> with Butler is good for automatization of tasks. <i>Otter.ai</i> – for capturing meetings in real-time. <i>Monday.com</i> – for projects management. <i>Zapier</i> – for connecting many apps. <i>X.AI</i> – for scheduling calls and meetings. <i>HubSpot</i> – for marketing and sales on autopilot. <i>Evernote</i> – for organisation notes and tasks. <i>Crystal</i> – for improving personality communication. <i>Microsoft Power BI</i> – for making data clear. <i>Hootsuite</i> – for managing social media and other things [55].
creativity	<i>Midjourney, DALL-E, and Adobe Firefly</i> are used to generate images and change typography and colours based on user prompts; <i>Synthesia</i> – to develop video projects; <i>Looka Logo Maker</i> – to create logos and brands [56]; <i>Miro AI</i> – to automatically create mental maps and summarize and turn ideas into effective roadmaps. <i>Startup.ai</i> – to generate ideas for start-ups; <i>Dime A Dozen</i> and <i>Feedback by AI</i> – to test ideas and receive feedback [57].

the performance of which requires having well-developed soft skills of students who major in IT, and 2) clarifying the feasibility of using AI tools in the professional training of future IT specialists to perform the tasks related to the applying soft skills. Two surveys were prepared (see Appendix A and Appendix B).

5.2.1. Results of survey analysis: perspectives of IT specialists. The 30 IT specialists participated in the survey. Most surveyed are men (73.3%), and women are a minor part of the respondents (26.7%). 40% of respondents have been working in the IT sphere for 10-20 years, and 30% of the respondents have working experience from 5 to 10 years. Note that 13.3% of surveyed IT specialists are luminaries of IT, as their working experience is more than 20 years. The same number of respondents have been working in IT for 3-5 years. And 3.3% have been working in IT for not over 3 years (figure 5). So, most surveyed participants are experienced professionals with extensive backgrounds.

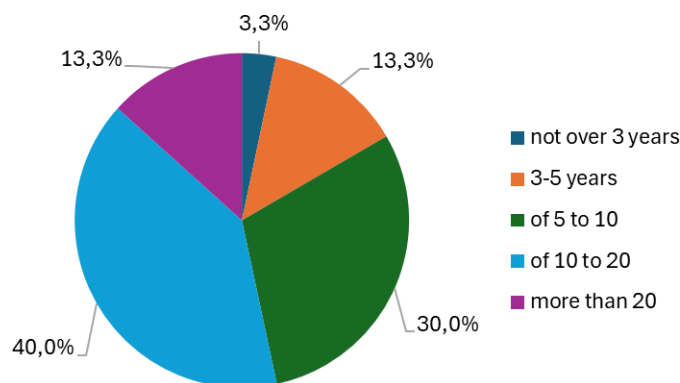


Figure 5. Work experience in the field of IT.

Most of the surveyed IT specialists have a master's degree in education (53.3%). Some respondents have a bachelor's degree in education (26.7%). Respondents have an academic degree in higher studies in IT, i.e., PhD, Post Doc, or Doctor of Science, or passed certified training courses, 3.3% each. So, most respondents obtained an academic degree in IT.

IT specialists who took part in the survey obtained different positions in the IT industry. Among them: web developers (20%), soft developers (16.7%), IT project managers (10%), system administrators (10%), engineers (6.7%), CEO of AI company (3.3%), etc. The respondents are from Ukraine (44.8%), Norway (17.2%), the USA (10.3%), Poland (6.9%), etc. The surveyed participants work for different famous companies and organisations, such as GSC Game World, Initial Force AS, Kaco Systems, Q-Free, Ciklum, BetterMe, SecurePractice, Sporttradar, Ninja Holdings, InfoTech, Intellope, Execon One, State Emergency Service, etc.

To the question, "Which AI tools / or AI-powered apps do you use to help with work tasks that do not involve programming skills (e.g., communication, organization, administration, etc.)", most of the IT specialists responded – AI chats (Microsoft Copilot, Gemini, ChatGPT, Assistant Poe) (86.7%). 26.7% of the surveyed participants use AI-powered apps to work on improving the text and for text correction (Grammarly, Quillbot); 16.7% – to efficiently work with the involvement of AI technology (Microsoft 365 Copilot); 10% – to work with projects (Taskade, Notion); 6.7% of respondents work with AI art generators (Night Cafe Creator, Microsoft Image Creator). Respondents were asked to state the AI tools that were not mentioned in the questionnaire. In response, the respondents stated that they use at work the following AI-powered tools such as Otter AI to make notes (3.3%), AI-powered software products, i.e., Eleven Labs (3.3%), and others. Some respondents do not need AI tools for performing tasks (13.3%)

and consequently do not involve programming skills. The unexpected outcome of the survey analysis was that, according to the respondents' responses, no one among surveyed specialists in IT has not used a voice assistant (Microsoft Cortana) for performing tasks at work, AI tools for productive work (ClickUp, Reclaim, Clara), and AI tools to make decisions (Fordi AI). Note that these tools were given as answer options in the questionnaire. It may signal that these products are not in demand among IT specialists. So, the appropriateness of their use in training CS specialists at universities is called into question.

In this context, it is essential to note that in total, 93.3% (40% – 50/50; 30% – partly yes; 23.3% – definitely yes) of the respondents are pleased one way or another with the results of the use of AI tools (AI-powered apps) in their professional work (figure 6).

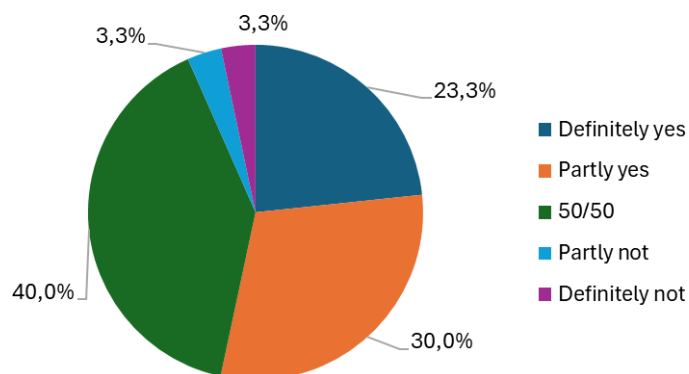


Figure 6. Representation of the satisfaction rating from IT specialists: this rating is related to the use of AI tools and applications based on AI at work.

The dilemma of whether to use AI-powered resources in the training process or not is still being discussed among the inhabitants. We asked the opinion of IT specialists on this matter. And it turned out that most of the surveyed IT professionals (precisely 89.7%; that is 53.3% – partly yes; 20% – 50/50; 16.7% – definitely yes) believe that AI is appropriate to use in the professional training of future IT specialists. IT specialists recognize that AI chats are valuable for training CS students. In particular, the survey participants stated that using specific/particular sets of AI tools to perform professional tasks is appropriate; hence, these sets of AI tools can be recommended for training CS students. The list of these AI tools and their percentage is in figure 7.

Moreover, IT professionals specified additional AI tools to help perform tasks requiring well-developed soft skills. Among their recommendations are the MLOPs plugin for Houdini (in the creation of content for video games) and ChatGPT and its wide options.

We asked IT specialists about the purpose of using AI tools in training CS students. Most of the respondents opted for two objectives: (1) AI tools allow students to optimize the learning process and reduce routine work to be able to focus on more creative tasks (63.3%), and (2) AI tools give ideas to IT students for their studying (53.3%). AI tools help make teaching and learning accessible and compelling to everyone (40%); also, AI can contribute to the development of the student's creativity and innovative thinking of students (40%), and using AI allows students to prepare for the future challenges of the IT industry and make them more competitive in the labor market (40%). Moreover, AI tools support the intention of IT students to learn humanitarian subjects to improve or develop their soft skills (33.3%), and AI tools make students aware of the latest technologies and trends (33.3%).

The IT specialists themselves use AI preferably for four reasons: (1) to automate repetitive and routine tasks (66.7%), (2) to search for information (56.7%); (3) to look for and find ideas (56.7%), (4) to solve professional tasks (53.3%), Note, that surveyed participants could choose

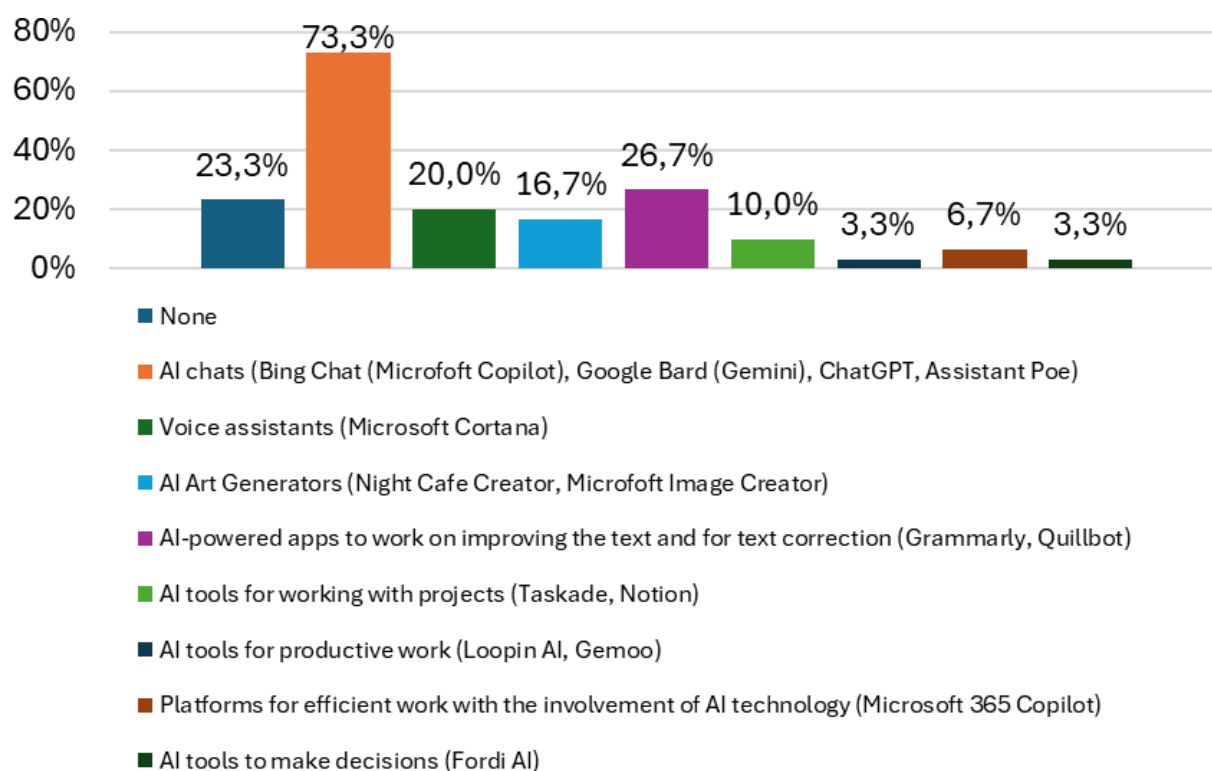


Figure 7. AI tools to perform professional tasks that require well-developed soft skills (IT specialists' views).

more than one option. Most IT specialists use AI in software development to enhance its functionality (43.3%). Moreover, based on the survey results, AI-driven solutions are helpful in developing automation and process optimization (27.6%). AI is also a great helper for data analysis and modelling (10.3%). Professionals equally (50.0% – 50/50) use AI for completing professional (the work with the code) and general (communication, organization, planning, administration) tasks. Some respondents (26.7%) use AI only for professional purposes, and the same number of respondents (23.3%) use AI only as a helper in planning or administrating the IT industry sphere. What matters is that 93.3% of the respondents said “Yes” to the appropriateness of using AI in the process of professional training of future IT specialists. For two participants in the questionnaire, it was hard to define whether AI is essential in training IT majors (figure 8).

One of the respondents stated that using AI in the training of CS students is not expedient. He explained his opinion in the following way: “*First of all, it's hard to name it AI at the current stage, but I see where it's coming from, and secondly, in my experience, teachers who use AI usually overlook some details and errors that it makes when it generates the content*”.

Thus, most of the IT specialists who participated in the survey use AI tools themselves while performing work that requires well-developed soft skills, and they recommend the use of AI tools in training CS students.

5.2.2. Results of survey analysis: perspectives of IT educators. In the survey 25 specialists in IT participated. Most of them have solid teaching experience: 32% of respondents have been teaching for 10-20 years, and exactly the same quantity of respondents has been teaching for more than 20 years. The new generation of teachers participated in the survey. Among them,

20% have been teaching for 5-10 years, and 16% have not over 3 years of experience (figure 9).

Most of the surveyed IT teachers are men (56%), but women are also a great part of the respondents (44%). Most of the surveyed IT teachers have a PhD degree in education. Post Doc or Doctor of Science degree 32% of teachers have. And 8% – Master's degree (figure 10).

IT educators who responded to the survey questions are mostly from Ukraine (68%). Also, IT educators from different countries shared their views on the topic under investigation. They live or work in Norway (16%), India (4%), Ethiopia and India (4%), China (4%) and Poland (4%), etc. Surveyed IT educators work for the following universities: Norwegian University of Science and Technology (NTNU), Lutsk National Technical University, University of Lodz, National University of Life and Environment of Ukraine, Lviv Polytechnic National University, Bannett University, Zhytomyr Polytechnic State University, Kharkiv National University of Radio Electronics, Taras Shevchenko National University of Kyiv, Wachemo University, National Institute of Technology Hamirpur, University of Stavanger, Islamic Azad University, Igor Sikorsky Kyiv Polytechnic Institute, etc.

To the question, “Which AI tools and/or AI-powered apps (of those listed below) do you use to help with work tasks?” IT teachers mostly (92%) answered that AI chats (Bing Chat (Microsoft Copilot), Google Bard (Gemini), ChatGPT, Assistant Poe). AI-powered apps (Grammarly, Quillbot) are also in great demand. 52% of respondents use them to improve the content of the text and for text correction. Microsoft 365 Copilot has value for IT teachers. 40% of respondents chose it. AI Art generators (Night Café Creator, Microsoft Image Creator) help 32% of respondents. 16% – use AI tools for working with projects (Taskade, Notion). Among the surveyed participants, 4% do not use Fordi AI – an AI tool commonly used to make decisions in the IT sphere and offered in the survey as a response option. Notably, some respondents added the names of AI tools that they use. Consequently, the AI search engine for research, Consensus, and Avidnote (AI for Research Writing, Reading, and Analysis) was added.

For the question “Are you pleased with the results of the use of these AI tools / AI-powered apps,” most of the surveyed IT teachers, particularly 44%, answered “Partly yes.” An equal quantity of respondents (28% / 28%) preferred the answers “50/50” or “definitely yes” (figure 11).

The question “Do you think AI tools can be used to perform professional tasks related to developing and showcasing IT students' soft skills in communication?” almost equal quantity of respondents answered “Definitely yes” – 36%, and “partly yes” – 32%. There were IT teachers who fifty-fifty agreed (20%) and those who answered “partly not” (12%).

As IT teachers think, AI tools can be used to perform professional tasks that require applying soft skills. IT teachers' opinions on this matter are divided in such a way: 76% of respondents suggest using AI chats for this, 56% of respondents offer to apply AI-powered apps (for improving

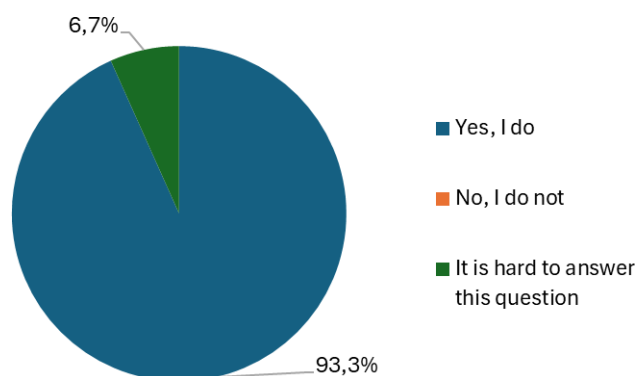


Figure 8. The use of AI in the process of training of CS students: IT specialists' views.

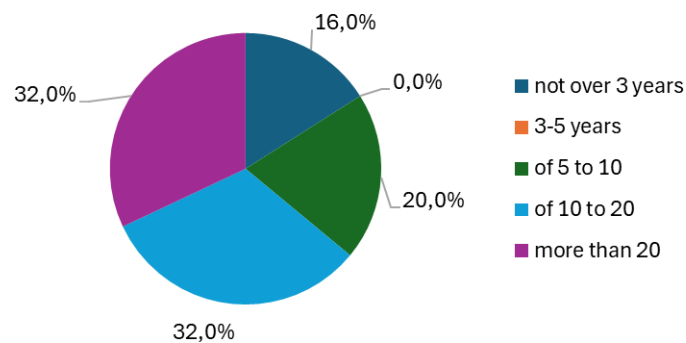


Figure 9. Teaching experience with CS students.

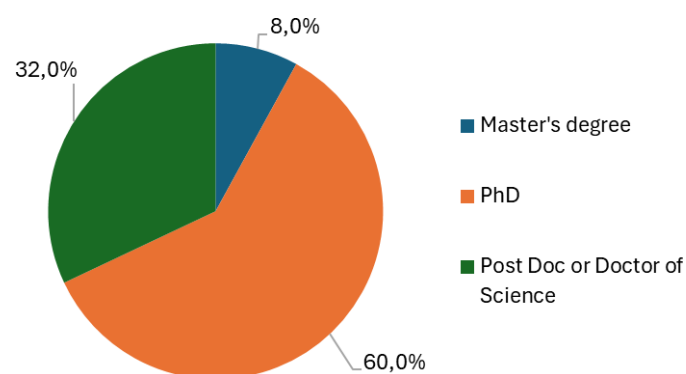


Figure 10. Academic title and/or academic degree of university teachers who teach CS students.

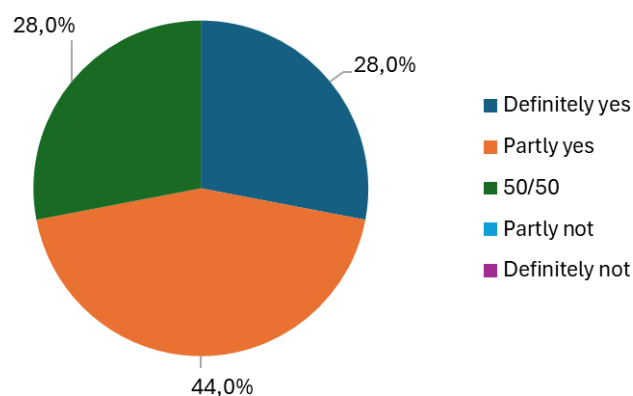


Figure 11. Representation of IT educators' satisfaction with the results of using AI tools (AI-based applications) in their professional work.

the content of texts and text correction); 32% – platforms for efficient work with the involvement of AI technology (e.g., Microsoft 365 Copilot) (figure 12). One participant stated that he also uses a language model called Claude.

For the question, “Could you add the categories of AI tools? Or could you mention the specific AI tools to perform professional tasks related to demonstration of soft skills?” the IT teachers proposed the following suggestions: (1) services for creating presentations, audio and video content; (2) DeepL online translator (deepl.com); (3) Gemini, Llama; (4) Overleaf, Plagiarism checkers, Github; (5) Azure AI language.

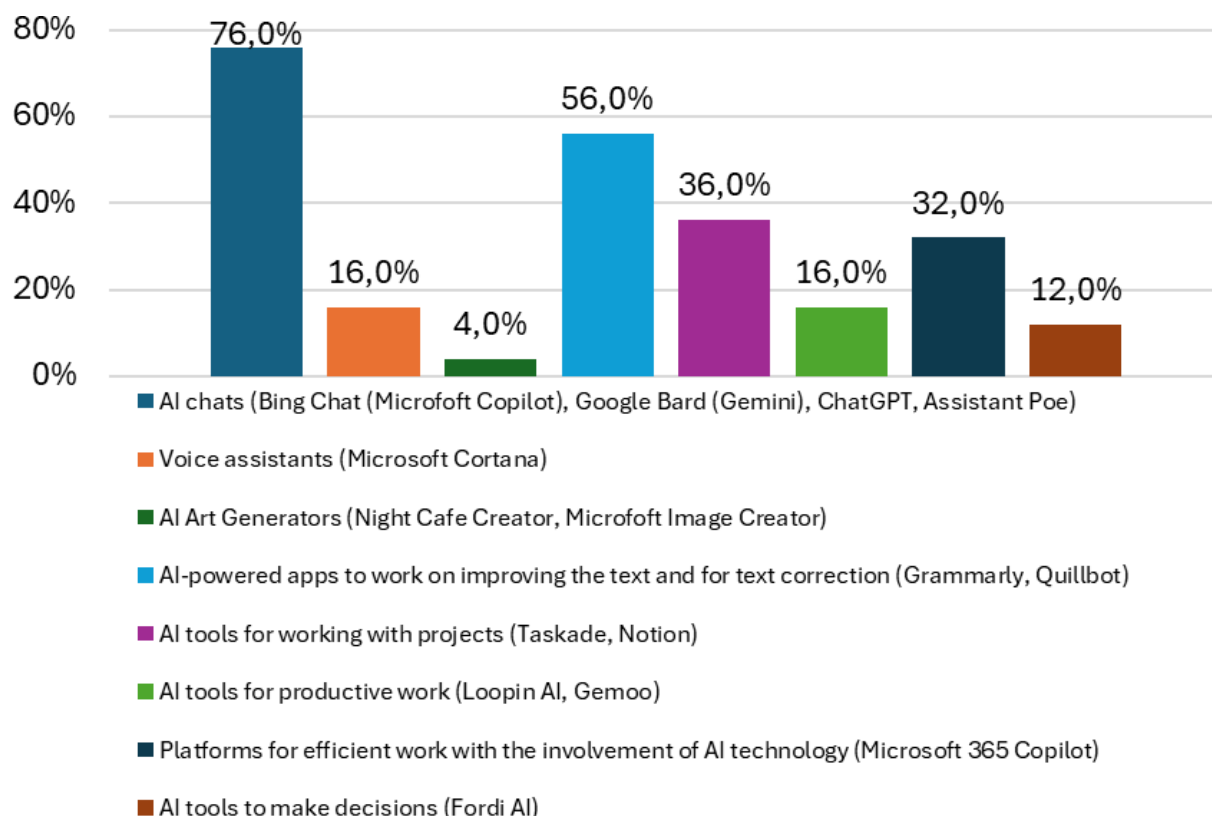


Figure 12. AI tools for performing work tasks that require well-developed soft skills (IT educators' views).

The main reasons for using AI in the process of training IT students were identified by respondents as follows: AI tools give the ideas for IT students for their studying (72%), AI tools make students aware of the latest technologies and trends (60%), AI tools allow students to optimize the learning process, reduce routine work to be able to focus on more creative tasks (60%), using AI allows students to prepare for the future challenges of the IT industry and make them more competitive in the labor market (56%), AI can contribute to the development of the students creativity and innovative thinking of students (44%), AI tools allow students to gain practical experience in solving real-world problems (40%), AI tools support the intention of the IT students to learn humanitarian subjects to improve or develop the soft skills (40%). Some respondents believe that AI tools are necessary to train IT students. In their view, AI tools help make teaching and learning accessible to everyone and practical (36%), AI tools foster the ability to work in a team, teach the students to work together in a team, utilizing various instruments and AI tools; allow to accelerate the development of effective communication (36%).

Most of the respondents – IT teachers – use AI to automate repetitive and routine tasks (76%) and to look for and find ideas (60%), to process and analyze large amounts of data (48%), and to search for information (44%), to solve professional tasks (44%). Some respondents, not many, use AI to receive personalized recommendations (40%), for entertainment purposes (32%), and to plan (perform) work tasks (28%).

Most of those surveyed support the inclusion of AI concepts in curricula designed to provide a comprehensive IT education (68%). Moreover, 56% of respondents think familiarizing IT students with AI during the lessons is essential. 44% of IT teachers use AI in IT education (propose tasks that require AI, e.g., scripts of negotiations). 40% of IT teachers support

integrating AI into preparation to develop soft skills and enhance the practical skills of IT students.

Most of the respondents IT educators (48% “agree” and 40% “definitely agree”) consider that it is appropriate to use AI in the process of professional training of future IT specialists. Only 12% are not sure about this decision and none of the respondents consider it inappropriate to use AI in the process of professional training of future IT specialists (figure 13).

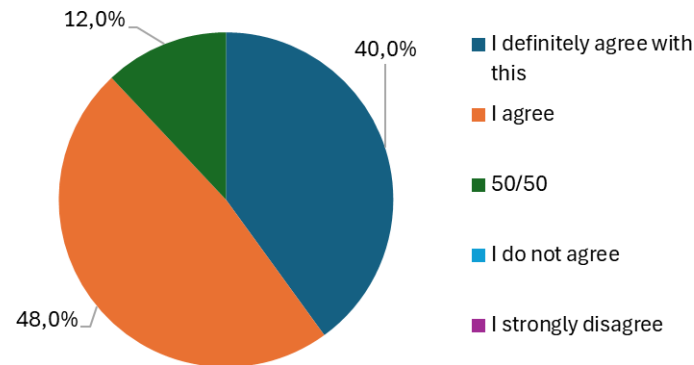


Figure 13. The use of AI in the process of professional training of future IT majors: IT educators' views.

Interesting? Beneficial? Useful? What do IT teachers think? Most respondents believe AI is interesting for students (48% “definitely agree” with this, the same number of the respondents, 48% – agree, and 4% chose “50/50”). AI benefits students, as 84% of the respondents think (60% of them – “definitely agree,” and 24% – “agree”). Also, 84% of the surveyed IT educators think that AI is useful for IT students (64% of them – definitely agree, 20% – agree).

5.2.3. Finding the correlation coefficients. In the process of the analysis of the opinions of IT specialists, we decided to determine the correlation between their experience of work in the IT sphere and the following two characteristics: 1) the satisfaction rating (figure 6) related to exploiting the AI tools and applications based on AI at work; 2) the conviction that the tools of AI can be used to perform professional tasks that require well-developed soft skills. To define the correlation coefficient, we use the Pearson correlation coefficient (PCC). The formula is (1):

$$r = \frac{\Sigma(X_i - X) \times (Y_i - Y)}{\sqrt{\Sigma(X_i - X)^2 \times \Sigma(Y_i - Y)^2}} \quad (1)$$

The terms in that formula are: r – the Pearson correlation coefficient; X_i and Y_i – the individual values of one (the other) variable (working experience for defining the value of the parameter of verification); X and Y – the mean values of the two variables.

We obtained the following correlation coefficients (PCC No.1):

- (i) for the satisfaction rating related to exploiting the AI tools and applications based on AI at work, the correlation coefficient is $r = 0.8$;
- (ii) for the conviction that the tools of AI can be used to perform professional tasks that require well-developed soft skills, the correlation coefficient is $r = 0.87$.

Considering the correlation coefficients PCC No.1, it can be concluded that there is a strong positive correlation ($r > 0$), in particular:

- (i) between the working experience in the IT sphere and the satisfaction level related to the use of AI tools and apps based on AI (the list of AI tools is offered in the survey as response options); so, $\rightarrow$ it has been defined that the more experience in IT the respondents have, the more their satisfaction with AI exploiting;
- (ii) between the working experience in the IT sphere and the conviction that AI tools can be used to perform professional tasks that require well-developed soft skills; so, $\rightarrow$ it has been defined that the more experience in IT the respondents have, the more they agree that AI tools/apps are valuable in the process of training CS students.

The next step is to define whether there is a correlation – PCC No.2 – between the work experience of IT educators and the following three characteristics: 1) the satisfaction level related to the use of AI tools and apps based on AI, 2) the conviction that the tools of AI can be used to perform professional tasks that require well-developed soft skills, 3) the feasibility of using AI in the process of training CS specialists.

We obtained the following correlation coefficients:

- (i) for the satisfaction rating related to exploiting the AI tools and applications based on AI at work, the correlation coefficient is $r = 0.84$;
- (ii) for the conviction that the tools of AI can be used to perform professional tasks that require well-developed soft skills, the correlation coefficient is $r = 0.74$;
- (iii) for the feasibility of using AI tools in the process of training CS students, the correlation coefficient is $r = 0.87$.

Considering the correlation coefficients PCC No.2, it can be concluded that there is a strong positive correlation ($r > 0$), in particular:

- (i) between the teaching experience of IT educators and the satisfaction level related to the use of AI tools and apps based on AI (the list of AI tools is offered in the survey as response options); so, $\rightarrow$ it has been defined that the more teaching experience the respondents have, the more their satisfaction with AI exploiting;
- (ii) between the teaching experience of IT educators and the conviction that AI tools can be used to perform professional tasks that require well-developed soft skills; so, $\rightarrow$ it has been defined that the more experience the teachers have, the more they agree that AI tools/apps are valuable for performing IT related tasks that require well-developed soft skills;
- (iii) between the teaching experience of IT educators and their opinion about the feasibility of using AI tools in the process of training CS students; so, $\rightarrow$ it has been defined that the more teaching experience the teachers have, the more they agree that the use of AI tools/apps in the training process is considered appropriate.

6. Conclusions

A controversial issue is integrating AI tools in higher education, particularly IT education, and the simultaneous development of AI majors' soft skills during the study process. The current study encompasses the use of AI to improve soft skills such as (1) communication skills, (2) teamwork and collaboration, (3) problem-solving skills, (4) interpersonal skills, (5) time management and organizational skills, (6) self-management skills, (7) leadership skills, and (8) creativity. The use of AI resources in IT majors' training process allows IT teachers to prepare their students for increasingly harsh market demands that widely implement AI resources in the IT industry (as evidenced by a survey of IT specialists).

The results of the current research allow us to answer the RQs:

- (Result 1). Today, there are AI tools that are applicable to deciding professional tasks in the IT industry, and they require applying well-developed soft skills. The results obtained from the analysis of scientific publications in Scispace and Scopus AI (table 2) and the analysis of the open-access publications on the Internet allow us to outline a range of AI tools that are available today and applicable to professional tasks in the IT sphere that require applying well-developed soft skills. Among these AI tools are AI Chats (mainly ChatGPT), voice assistants, AI art generators (mainly Midjourney), intelligent tutoring systems, personalized AI guidance and text generation (mainly Grammarly), and tools for teamwork and collaboration (primarily Notion). Moreover, other AI tools applicable to the IT industry exist in the market today, particularly for conducting interpersonal communication, dealing with workplace challenges, time management and self-management, and completing tasks that require applying leadership and creativity skills. Simultaneously, IT specialists and university teachers consider these AI tools essential for work and study, based on the survey results.
- (Result 2). The survey confirmed the theoretical conclusions that most of the IT specialists and IT educators use AI Chats (86.7% and 92%, respectively), as well as AI tools for improving the text and for text correction (Grammarly, Quillbot) (26.7% and 52%). A much smaller percentage of IT specialists (16.7%) are using platforms for efficient work with the involvement of AI technology (Microsoft 365 Copilot), but 40% are IT educators using it. 10% of IT specialists use AI tools at work, and 16% of university teachers who work with CS students use AI tools during training. AI art generator tools are preferred by IT educators (32%) compared with IT specialists (6.7%). So, IT teachers are more enthusiastic about using AI tools and/or AI-powered apps to help with work tasks. Based on the work experience of IT specialists and IT teachers, AI tools are helpful at work and in study. First and foremost, it is about AI chats (73.3% and 76.0%) and AI-powered apps and their use to work on improving text and text correction (26.7% and 56.0%). Respondents also noted the feasibility of applying AI tools for project completion (10.0% and 36.0%). Platforms for efficient work with the involvement of AI technology (6.7% and 32.0%) are also essential resources today. A much smaller percentage of respondents – IT specialists and university teachers who work with CS students – suggest using AI tools such as voice assistants (20.0% and 16.0%), AI art generators (16.7% and 4.0%), AI tools for productive work (3.3% and 16.0%), AI tools to make decisions (3.3% and 12.0%).
- (Result 3). Based on the survey results, we can imply that the vast majority of IT specialists who participated in the survey support the idea that AI tools can be used to train CS students to perform professional tasks by applying well-developed soft skills (53.3% of IT specialists answered “Partly yes”, 20% – 50/50, and 16.7% – “Definitely yes”; 36% IT educators answered “Definitely yes”, 32% “Partly yes,” and 20% – 50/50). AI tools can be used for soft skills development during the training process of IT majors. Among the “FOR” arguments claimed by IT educators are students’ interest (48% – definitely agree, 48% – agree, and 4% – 50/50). In the process of calculating correlation coefficients, we discovered the following patterns: (1) the more experienced IT specialists and IT educators are, the more they are satisfied with the use of AI technology at work; (2) the more experienced IT specialists and IT educators are, the more they agree that AI tools/apps are valuable for performing IT related tasks that require well-developed soft skills; (3) the more IT educators experience the teachers have, the more they have become convinced that the use of AI tools/apps in the training process is appropriate.

Given the sufficient number of AI tools available today online, considering the requirements of the modern labor market that states multiple tasks for the IT specialist, the successful performance of which requires good knowledge of new AI technology along with well-developed soft skills, also taking into consideration the fact that the experience of AI-power implementation in the process of training CS students exists; we conclude that the use of AI tools in the process of training CS students is relevant. Consequently, this implementation contributes to developing soft skills among CS students, which is in demand in the modern labor market. In this regard, further research aims to clarify the efficiency of the use of AI tools for developing soft skills among CS students.

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Appendix A. Survey “The points of view of IT specialists on Artificial Intelligence (AI), AI tools, AI-powered apps and their applicability for the development of the soft skills of IT students”

Block 1: Characteristics of the participants

1. What is your gender identity?
 - Male
 - Female
 - Non-binary
 - Prefer not to say
2. What has been your experience of working in the IT field?
 - not over 3 years
 - 3-5 years
 - of 5 to 10
 - of 10 to 20
 - more than 20
 - other
3. Are you a qualified expert in the IT field? What degree do you have?
 - Bachelor’s degree
 - Master’s degree
 - PhD
 - Post Doc or Doctor of Science
 - other

Block 2: The obtained position in the IT company, the country, and the company

1. The obtained position in the company ...
 - Engineer
 - Software developer/ Software Development Manager
 - Systems Administrator
 - Database administrator
 - Cybersecurity analyst
 - IT Project manager
 - Web developer
 - Quality assurance engineer
 - Cloud architect
 - IT Manager/Director
 - Chief Information Officer (CIO)
 - Chief Technology Officer (CTO)
 - other
2. The country you are working in ...
 - Ukraine
 - Poland
 - Germany
 - USA
 - China
 - Slovakia
 - Spain
 - Norway
 - other
3. The name of the IT company you work for ...

Block 3: The use of AI in your own professional activities in the IT sphere

1. What AI tools / or AI-powered apps do you use to help with work tasks that do not involve programming skills (e.g., communication, organization, administration, etc.)?
 - I don't use AI tools for it
 - AI chats (Bing Chat (Microsoft Copilot), Google Bard (Gemini), ChatGPT, Assistant Poe)
 - Voice assistants (Microsoft Cortana)
 - AI Art Generators (Night Cafe Creator, Microsoft Image Creator)
 - AI-powered apps to work on improving the text and for text correction (Grammarly, Quillbot)
 - AI tools for working with projects (Taskade, Notion)
 - AI tools for productive work (ClickUp, Reclaim, Clara)
 - Platforms for efficient work with the involvement of AI technology (Microsoft 365 Copilot)
 - AI tools to make decisions (Fordi AI)
 - other
2. Are you pleased with the results of the use of these AI tools / AI-powered apps?
 - Definitely yes
 - Partly yes

- 50/50
- Partly not
- Definitely not

Block 4: The use of AI professional training of future IT specialists

1. Do you agree that AI tools can be used in training IT majors to perform professional tasks that require well-developed soft skill?
 - Definitely yes
 - Partly yes
 - 50/50
 - Partly not
 - Definitely not
2. Which AI tools do you think should be used to perform professional tasks that require well-developed soft skill?
 - None
 - AI chats (Bing Chat (Microfoft Copilot), Google Bard (Gemini), ChatGPT, Assistant Poe)
 - Voice assistants (Microsoft Cortana)
 - AI Art Generators (Night Cafe Creator, Microfoft Image Creator)
 - AI-powered apps to work on improving the text and for text correction (Grammarly, Quillbot)
 - AI tools for working with projects (Taskade, Notion)
 - AI tools for productive work (Loopin AI, Gemoo)
 - Platforms for efficient work with the involvement of AI technology (Microsoft 365 Copilot)
 - AI tools to make decisions (Fordi AI)
 - other
3. Could you add the categories of AI tools? Or could you mention the specific AI tools to perform professional tasks related to the demonstration of soft skills? If yes, indicate/type them below:

...

Block 5: The purpose of the use of AI in the preparation of the IT students and in your own professional activities

1. What are the reasons for using AI in the preparation of the IT students?
 - AI tools support the intention of IT students to learn humanitarian subjects to improve or develop the soft skills
 - AI tools give ideas for IT students for their studying
 - AI tools make students aware of the latest technologies and trends
 - AI tools give students the opportunity to gain practical experience in solving real-world problems
 - AI tools help make teaching and learning accessible to everyone and effective
 - AI tools foster the ability to work in a team, allow to accelerate the development of effective communication
 - AI can contribute to the development of the student's creativity and innovative thinking of students
 - Using AI allows students to prepare for the future challenges of the IT industry and make them more competitive in the labour market

- AI tools allow students to optimize the learning process, reduce routine work to be able to focus on more creative tasks
 - other
2. Why do you use AI?
 - to process and analyze large amounts of data
 - to solve professional tasks
 - to receive personalized recommendations
 - to automate the repetitive and routine tasks
 - for entertainment purpose
 - to search for information
 - to look for/find ideas
 - to plan (perform) work tasks
 - other
 3. How do you use AI in your own professional activities?
 - I use AI in software development to enhance its functionality
 - I use AI for data analysis and modelling
 - I use AI-driven solutions for developing automation and process optimization
 - I use AI tools for leveraging cybersecurity and the automated detection of threats
 - other
 4. What tasks do you preferably complete using AI technology: professional or general?
 - Professional tasks
 - Both: 50/50
 - General tasks
 5. Do you consider that it is appropriate to use AI in the process of professional training of future IT specialists?
 - Yes, I do
 - No, I do not
 - It is hard to answer the question
 6. If you answered “No, I do not” or “It is hard to answer this question” to the previous question, then please explain your point of view.

Appendix B. Survey “The points of view of IT educators on Artificial Intelligence (AI), AI tools, AI-powered apps and their applicability for the development of the soft skills of IT students”

Block 1: Characteristics of the participants

1. How long have you been working as an IT teacher?
 - not over 3 years
 - 3-5 years
 - of 5 to 10
 - of 10 to 20
 - more than 20
2. What is your gender identity?
 - Male
 - Female

- Non-binary
 - Prefer not to say
3. What degree do you have?
- Master's degree
 - PhD
 - Post Doc or Doctor of Science
 - other

Block 2: The country and the university

1. The country you are working in ...
- Ukraine
 - Poland
 - Germany
 - USA
 - China
 - Slovakia
 - Spain
 - Norway
 - other
2. The university you work for ...

Block 3: The use of AI in your own professional activities in the IT sphere and in the IT students' training

1. Which AI tools / or AI-powered apps do you use to help with work tasks?
- I don't use AI tools for it
 - AI chats (Bing Chat (Microfoft Copilot), Google Bard (Gemini), ChatGPT, Assistant Poe)
 - Voice assistants (Microsoft Cortana)
 - AI Art Generators (Night Cafe Creator, Microsoft Image Creator)
 - AI-powered apps to work on improving the text and for text correction (Grammarly, Quillbot)
 - AI tools for working with projects (Taskade, Notion)
 - AI tools for productive work (ClickUp, Reclaim, Clara)
 - Platforms for efficient work with the involvement of AI technology (Microsoft 365 Copilot)
 - AI tools to make decisions (Fordi AI)
 - other
2. Are you pleased with the results of the use of these AI tools / AI-powered apps?
- Definitely yes
 - Partly yes
 - 50/50
 - Partly not
 - Definitely not

Block 4: The use of AI professional training of future IT specialists

1. Do you agree that AI tools can be used in training IT majors to perform professional tasks that require well-developed soft skill (particularly, communication skills)?

- Definitely yes
 - Partly yes
 - 50/50
 - Partly not
 - Definitely not
2. Which AI tools do you think should be used to perform professional tasks that require well-developed soft skill?
- None
 - AI chats (Bing Chat (Microfoft Copilot), Google Bard (Gemini), ChatGPT, Assistant Poe)
 - Voice assistants (Microsoft Cortana)
 - AI Art Generators (Night Cafe Creator, Microfoft Image Creator)
 - AI-powered apps to work on improving the text and for text correction (Grammarly, Quillbot)
 - AI tools for working with projects (Taskade, Notion)
 - AI tools for productive work (Loopin AI, Gemoo)
 - Platforms for efficient work with the involvement of AI technology (Microsoft 365 Copilot)
 - AI tools to make decisions (Fordi AI)
 - other
3. Could you add the categories of AI tools? Or could you mention the specific AI tools to perform professional tasks related to the demonstration of soft skills? If yes, indicate/type them below:
- ...

Block 5: The purpose of the use of AI in the preparation of the IT students and in your own professional activities

1. What are the reasons for using AI in the preparation of the IT students?
- AI tools support the intention of IT students to learn humanitarian subjects to improve or develop the soft skills
 - AI tools give ideas for IT students for their studying
 - AI tools make students aware of the latest technologies and trends
 - AI tools give students the opportunity to gain practical experience in solving real-world problems
 - AI tools help make teaching and learning accessible to everyone and effective
 - AI tools foster the ability to work in a team, allow to accelerate the development of effective communication
 - AI can contribute to the development of the student's creativity and innovative thinking of students
 - Using AI allows students to prepare for the future challenges of the IT industry and make them more competitive in the labour market
 - AI tools allow students to optimize the learning process, reduce routine work to be able to focus on more creative tasks
 - other
2. Why do you use AI?
- to process and analyze large amounts of data
 - to solve professional tasks

- to receive personalized recommendations
 - to automate the repetitive and routine tasks
 - for entertainment purpose
 - to search for information
 - to look for/find ideas
 - to plan (perform) work tasks
 - other
3. How do you use AI in your own professional activities?
- I support incorporating AI concepts into curriculum design for comprehensive IT education
 - I support integrating AI into preparation to develop soft skills and enhance practical skills of IT students
 - I use AI in IT education (I propose tasks that require the use of AI; e.g., scripts of negotiations)
 - I think that familiarisation of IT students with AI during the lessons is essential
 - other
4. Do you consider that it is appropriate to use AI in the process of professional training of future IT specialists?
- I definitely agree with this
 - I agree
 - 50/50
 - I do not agree
 - I strongly disagree
5. If you answered “No, I do not” or “It is hard to answer this question” to the previous question, then please explain your point of view.

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The impact of AI on the development of cognitive competence in gifted youth

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Abstract. In the modern world, the rapid development of artificial intelligence significantly influences the demands on the cognitive competence of young people. The formation of cognitive competence becomes an essential factor in the successful adaptation of young people to new conditions of work and life. This requires not only critical thinking and the ability to take a creative approach but also the skill to make decisions under conditions of uncertainty. The development of cognitive competence serves as a foundation for cultivating flexible thinking skills, allowing young people to quickly adapt to technological and social changes. Furthermore, cognitive competence improves the competitiveness of young professionals in the labor market, empowering them to address global challenges by integrating innovative approaches and cutting-edge technologies. Young people must acquire skills in working with large datasets, algorithms, and analytical tools, positioning cognitive competence as a cornerstone of their professional growth. This study aims to analyze the impact of participation in the development of artificial intelligence projects on the cognitive skills of gifted students of the “Polit” Science Lyceum. The study is based on the analysis of student projects presented in scientific competitions to evaluate their effect on the development of scientific thinking, critical analysis, and decision making skills in the context of working with AI. The research results confirm the positive impact of project-based work in the field of AI on students’ cognitive competence, particularly in the context of solving complex scientific problems and understanding the nature and manageability of AI technologies. Consequently, participating in AI project development fosters the cognitive competence of gifted youth, contributing not only to their success, but also to advances in science and society.

1. Introduction

Modern realities are characterized by the rapid development of technologies, particularly AI [1, 2], which significantly transforms the requirements for educating young people. Information overload, difficulties in adapting to new technologies, and the constant transformation of the labor market demand a high level of cognitive competence from the younger generation. The importance of cognitive skills lies in their ability to facilitate effective learning, rapid acquisition of new knowledge, and adaptation to changing life and work conditions. Cognitive competence encompasses the ability to process information effectively, make rational decisions, and adapt to changing circumstances. This aspect of competence includes not only knowledge and skills, but also the ability to think critically, creative approaches, and strategic planning. In the context of the modern world, where IT and rapid change are the norm, cognitive competence plays a crucial role in the development of successful and adaptive individuals. It is a key factor for



successful learning, making informed decisions, generating ideas, and strategic planning.

At the same time, the participation of gifted youth in scientific projects in the field of AI remains under-researched. The necessity to analyze the effectiveness of such projects is relevant, as they contribute not only to the development of critical thinking, research skills, and the ability to solve complex problems, but also to understanding the nature and manageability of AI technologies.

This study aims to determine the impact of gifted students' participation in extracurricular scientific projects in AI on the development of cognitive competence. Specifically, it examines how working on innovative software development fosters scientific thinking, creativity, and adaptability to the challenges of the modern technological environment.

In contemporary research, cognitive competence is considered through various approaches, particularly as an "integrative formation through which the objective world and oneself are comprehended, leading to the generation of new ideas and the creation of new products in a specific field of knowledge" [3]. Sun and Hui [4] emphasizes two components of cognitive competence – critical and creative thinking. At the same time, Shek and Lu [5] highlights the role of cognitive competence in ensuring the harmonious development of youth and the formation of effective leadership. In this context, it is important to note that the rapid development of AI changes the requirements for young people's cognitive skills, fostering the formation of new approaches to learning and adaptation to constant technological changes. Thus, research aimed at evaluating the impact of student participation in AI projects is especially relevant for identifying methods to develop cognitive competence among young people. Developing these skills is a critical factor not only for students' personal growth but also for their ability to address the global challenges of the present day.

Considering the process of developing cognitive competence through the lens of enhancing research skills and scientific thinking, it is important to highlight a nationwide study organized by the Projector Creative & Tech Institute and the Junior Academy of Sciences of Ukraine (JAS), supported by the research company Factum Group Ukraine and the Ministry of Education and Science of Ukraine. The study aimed to assess the implementation of AI in Ukrainian schools and identify the opportunities for its further use in the educational process. This survey, conducted from September to October 2023, involved over 3,000 participants, including 1,747 teachers and 1,443 students in grades 8–11 [6]. Teachers expressed concerns about potential negative consequences of AI implementation, such as a decline in students' development, an increase in cases of plagiarism, and unethical use of technology. Educators also admitted a lack of understanding of the principles behind AI, which raises concerns about their ability to effectively engage with new technologies. Meanwhile, most students believe that AI can significantly improve the learning process, making it more engaging and exciting. They also expressed a desire to receive guidance from teachers on the ethical use of AI, highlighting its advantages and disadvantages. This data highlights the need for more in-depth research into the impact of AI on the development of student's cognitive competence, particularly among youth capable of mastering information technologies. Exploring the prospects of integration of AI into the educational process may aid in adapting curricula and creating resources that ensure the effective and ethical use of technologies in learning.

To ensure the effective development of cognitive competence among young people, it is essential to consider approaches aimed at integrating AI into the educational process. In this context, Aydın and Yurdugül [7] proposes the development of an AI-integrated curriculum for intellectually gifted students. The objective of this study is to develop a structured AI curriculum designed specifically for students who are just beginning to explore this field, without requiring prior programming knowledge. The primary topics of the program include an introduction to AI, probability, supervised and unsupervised learning, clustering, and other key concepts. The authors emphasize the need to integrate these topics into curricula to support the development

of cognitive competence and the professional potential of gifted students.

This idea is further developed in the study [8], where Williams et al. explore the improvement and adaptation of AI curricula, considering new challenges such as the COVID-19 pandemic. The study examines methods that assist teachers with varying levels of expertise in integrating AI elements into their teaching. The program, adapted for the online format, consisted of five sessions during which teachers and researchers conducted joint lessons. The results showed high student engagement and highlighted the importance of ethical discussions regarding AI use. Teachers noted the need for further improvement of materials and adaptation of the curriculum for different student groups. This research provides valuable insights and suggestions for improving AI education in middle school, addressing new challenges and the needs of both teachers and students.

Further analysis of the impact of AI on the development of young people's cognitive skills is presented by Tolochko et al. [9]. It emphasizes the importance of integrating AI into educational programs to help students critically evaluate information, foster creativity, and develop interpersonal communication skills. Recommendations for educators include fostering critical thinking, enhancing adaptability, and ensuring academic integrity. This highlights AI's role in shaping students' cognitive competence, which is essential for their preparation for the technological environment. It is worth noting that this approach aligns with the concept of strategic learning, where dynamic learning and adaptation to change are key to ensuring a competitive advantage, as demonstrated in the study [10].

2. Materials and methodology of the study

The study is based on the analysis of scientific projects developed by students of the "Polit" Science Lyceum over the past few years. The materials of the study include projects implemented using both proprietary and third-party neural network models and natural language processing technologies. The analyzed projects covered technologies such as swarm algorithms, artificial neural networks, DialogFlow, EdLeNet, YOLOv7, YOLOv8, MediaPipe, and ChatGPT, which were used for object recognition, gesture recognition, and voice command recognition under various conditions.

The primary research method was the systematization and analysis of projects demonstrating different approaches to the application of AI for solving specific tasks. The complexity of the tasks, the algorithms applied, and their contribution to the development of students' cognitive competence were assessed based on the evaluation criteria used in the competitive selection process of the JAS [11]. In particular, the following metrics were taken into account: justification of the research topic selection, systematic approach and completeness in topic coverage, ability to think critically and formulate conclusions, consistency of completed tasks with the research objectives, and adherence to scientific style and structural formatting requirements.

During the analysis of the studied projects, attention was paid to several key aspects related to the development of cognitive competence. In particular, critical thinking was reflected in students' ability to formulate and justify problems requiring solutions, while creative thinking was demonstrated through the creation of innovative solutions and the adaptation of existing algorithms to specific conditions of task execution. Analytical skills were evaluated based on the results of data processing and the choice of optimal approaches for model training, whereas scientific thinking was observed in the formulation of hypotheses, conducting experiments, and further analysis of their results. Research skills were manifested in the independent selection of tools and technologies necessary for the successful implementation of the projects.

In the experimental part of the study, the process of developing cognitive competence among student project authors was assessed through observation using rating scales of behavioral indicators related to intellectual, creative, and practical giftedness [12].

The study involved students from the "Polit" Science Lyceum specializing in mathematics and

informatics, who demonstrated a sustained interest in project-based activities in the field of AI. The level of giftedness was determined using the “Personal Factors of Giftedness” method [13], which evaluates key personal traits such as: supra-situational activity (the ability to go beyond given conditions), risk-taking propensity, intuition, the level of creative disorganization, and reproductive activity. All students showed high levels of cognitive engagement, critical thinking, and readiness to work in conditions of uncertainty – traits that, according to the assessment method, indicate intellectual giftedness. The survey results revealed high levels of supra-situational activity, intuitive thinking, low reproductive dependence, and a strong inclination toward risk, which overall characterize the participants as students with strong research potential and flexible thinking.

3. Results and discussion

For many years, students of the “Polit” Science Lyceum have shown interest in scientific developments in the field of AI, conducting independent research in this area and presenting their results at regional, national, and international competitions for student scientific projects. Among the most popular competitions are the National Competition of Research Projects organized by the JAS, which features a dedicated section on “Artificial Intelligence Systems and Technologies”, and international high school project competition about environmental issues, the GENIUS Olympiad.

The scientific advisor’s work with students in the field of AI research involves familiarizing them with the latest achievements in the field and encouraging them to independently develop practical computer projects based on their acquired knowledge. This approach fosters the development of cognitive competence in young researchers. The range of scientific interests and the level of functionality of student projects have been gradually expanding. Experience is accumulated and transferred from previous participants in research, starting from the selection of the research direction to its practical implementation. Developing computer projects also requires students to master new programming technologies, utilize cloud-based tools, and implement existing models developed by third parties.

Below are descriptions of student AI projects presented in recent years that gained recognition at various levels of intellectual competitions.

In 2017, a student from the “Polit” Science Lyceum presented a project titled “Computer Implementation of the Algorithmic Model of an Optimization Problem Based on Swarm Intelligence” at the JAS competition in the “Information Systems, Databases, and Artificial Intelligence Systems” section. The research object was optimization processes based on swarm intelligence, and the subject was swarm intelligence algorithms for enabling game AI during the development of a strategic computer game.

In the course of the study, the criteria for applying swarm algorithms to problem-solving in various fields of human activity were identified, an algorithmic model of a game-based task was developed, and the potential of using the ant colony algorithm for its implementation was determined.

The computer game “Battle of Generals”, developed on the basis of the algorithmic model, featured a game AI capable of selecting optimal strategies during gameplay.

Figure 1 shows the program window of “Battle of Generals” after a victory by the character controlled by game AI.

The game was developed for participation in the XV National Tournament of Young Programmers in 2016 and was presented in 2017 at the regional stage of the JAS competition defense, where it earned a 3rd-degree diploma.

The project demonstrates the development of cognitive competence through creation of an algorithmic model, establishment of criteria for applying artificial intelligence algorithms, and adaptation of the ant colony algorithm, all of which foster analytical and creative abilities.

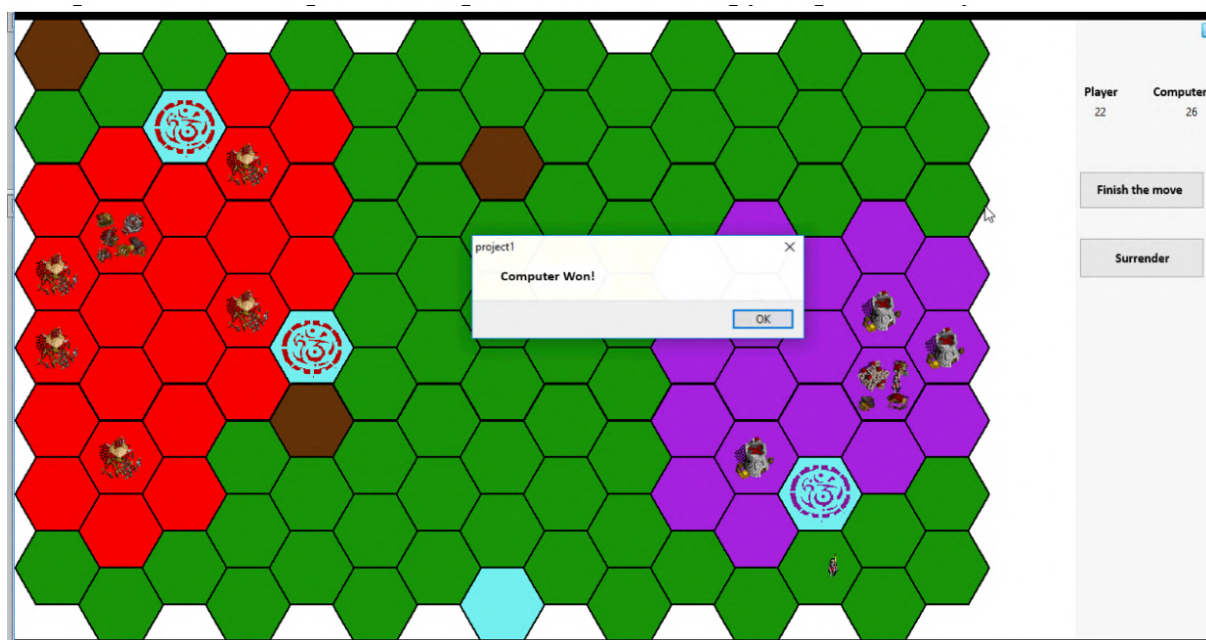


Figure 1. Program window of “Battle of Generals”.

The student reviewed the theoretical foundation and conducted experiments and testing, demonstrating critical thinking and a research-oriented approach. Independent selection of tools and development of the game prototype confirm the ability to plan rationally and implement ideas. The skills of analysis, technology adaptation, and presentation of results highlight the development of scientific thinking. The project reflects the comprehensive development of creative, critical, and analytical thinking through research activities.

One of the most powerful AI mechanisms is artificial neural networks. Their development and use in projects did not escape the attention of lyceum students.

In 2018, a student of the "Polit" Science Lyceum presented a research project titled "Implementation of a Handwritten Text Recognition System" at the JAS competition. The research object was the process of handwritten text recognition, while the subject was artificial neural networks as a tool for recognizing handwritten symbols. The goal of the research was to model, develop, and train an artificial neural network capable of recognizing handwritten symbols.

In the course of the study, the student became familiar with the concept of artificial neural networks, and their components, analyzed the architecture of neural networks, and studied training methods. He developed a mathematical model and computer implementation of a neural network for recognizing digits from handwritten input.

The Digit Recognition program was developed in Python without the use of pre-existing external neural network models to provide a deeper understanding of the processes involved in modeling, training the network, and interpreting the results obtained from its application.

Figure 2 shows the program's interface after recognizing an input digit.

The presented project received a third-degree diploma at the regional stage of the JAS research project competition in 2018.

The project facilitated the development of critical thinking by clearly defining the research problem, objective, and scope. Developing a custom mathematical model for the neural network fostered creative thinking and the ability to find innovative solutions. Analytical skills were demonstrated in evaluating the model's performance through experiments and recognition

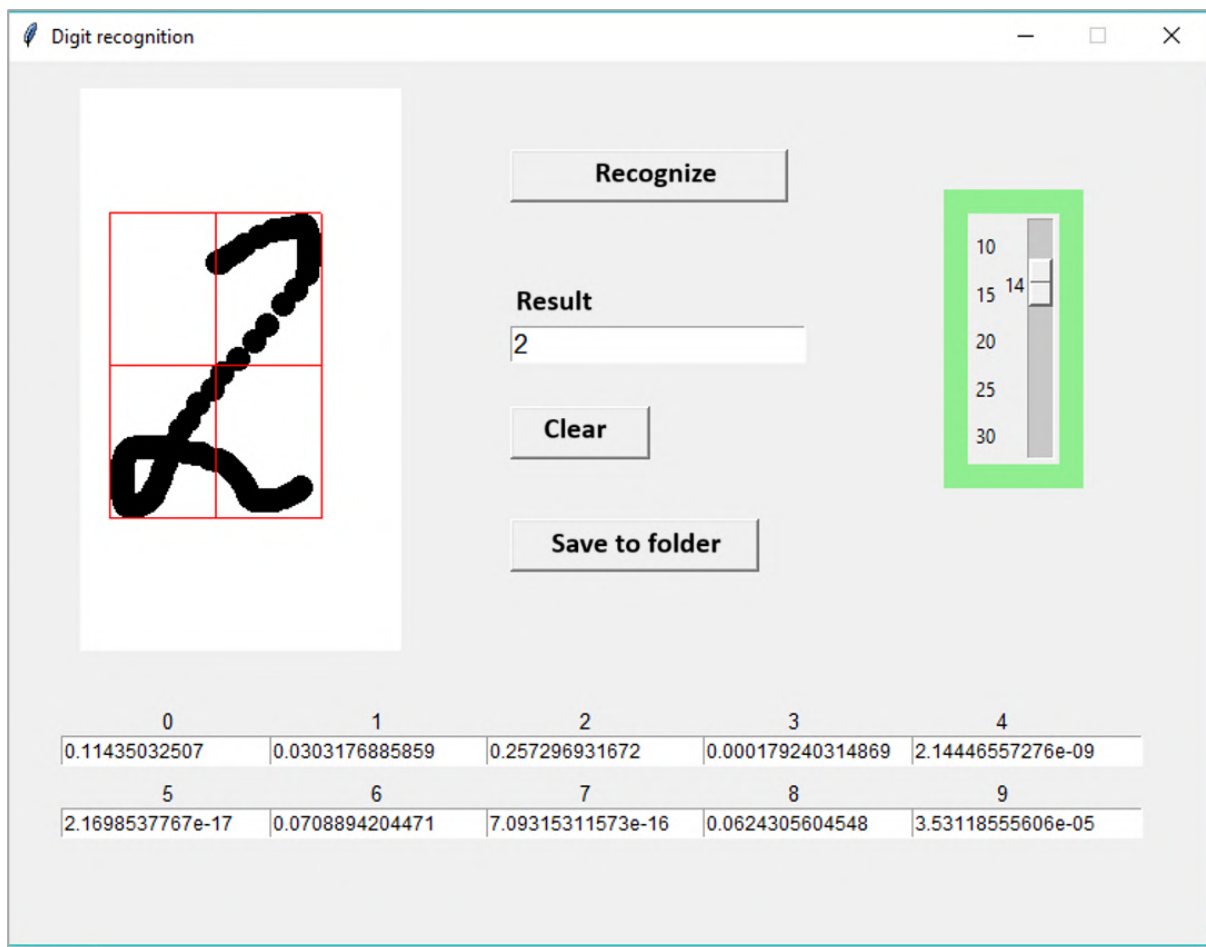


Figure 2. Window of the program after recognizing a digit.

accuracy. Completing the full cycle of scientific research underscored the advancement of scientific thinking. Independently creating algorithms and software proved the ability to apply theoretical knowledge to real-world problems by combining theory with practice.

The next step in developing custom neural networks and enhancing the functionality of AI-based systems was the research project “Mathematical Expression Recognition System”, presented at the JAS regional competition in 2020. Unlike the previous project, the developed program employs several neural networks with a more complex architecture. The system’s objective was to recognize handwritten mathematical expressions and it’s the task to calculate the values of the entered expressions. The system consists of three neural networks: the first for recognizing digits, the second for mathematical operation symbols and brackets, and the third for Latin letters in mathematical functions and constants.

The neural networks in the NeuroMath program were independently modeled by the student using the Python programming language.

Figure 3 shows the program window of the NeuroMath after recognizing the entered mathematical expression and calculating its value.

The NeuroMath project was awarded a second-degree diploma at the regional stage of the JAS competition in 2020.

The project significantly contributed to the development of the student’s cognitive competencies through several key aspects. Critical thinking was cultivated by analyzing relevant

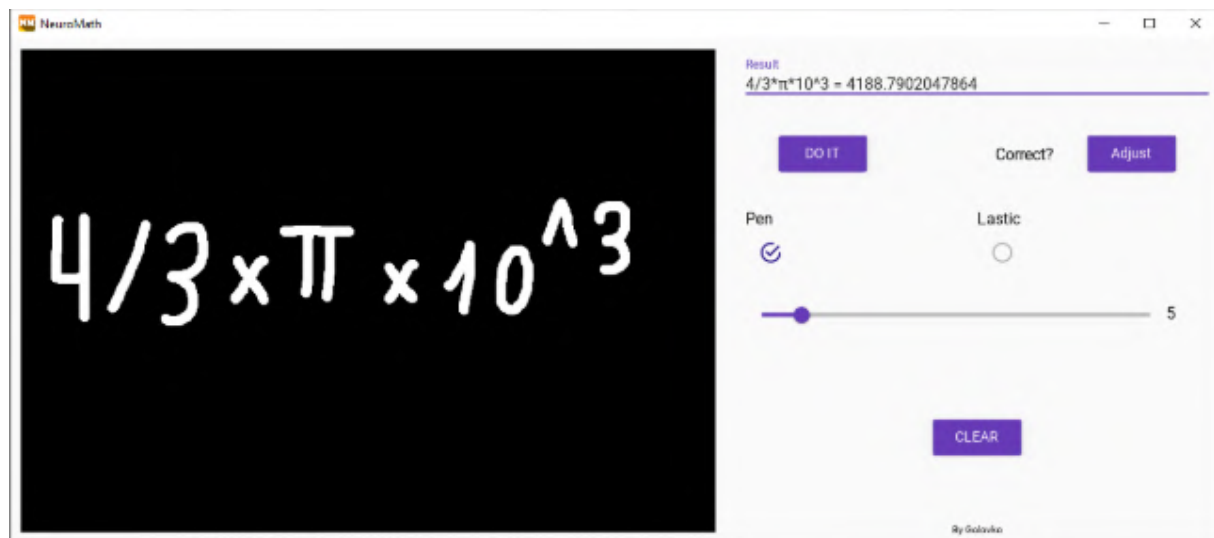


Figure 3. Window of the NeuroMath program.

problems and formulating clear research objectives. Creative thinking was demonstrated in the independent development of models for three neural networks, deepening the understanding of artificial intelligence mechanisms. Analytical skills were demonstrated in evaluating the effectiveness of models based on data processing and achieving high accuracy. Scientific reasoning was applied in formulating hypotheses, conducting experimental validation, and refining results. Research skills were highlighted by the independent application of modern technologies to solve practical problems.

A different approach to designing an AI-based system was implemented in 2021 in the research project titled “A Personal Assistant for Smart Home Control”. The object of the study was the process of managing a smart home, while the subject of the research focused on the technologies used for smart home control. The aim of the study is to develop a digital personal assistant with a visual interface for voice-controlled smart home management, based on the analysis of smart home technologies and voice message processing tools.

The study explored the specific features of the concept of a smart home and identified its components. The interaction schemes and protocols of smart home elements, which facilitate the automation of household tasks, were analyzed [14–16]. Technologies for voice command processing, visualizing the assistant’s interface, and enabling the assistant’s interaction with the smart home’s hardware components were selected.

In contrast to the previous projects, this one did not involve the development of a proprietary neural network. Instead, to implement the logic of the assistant responsible for recognizing the meaning of natural language commands, the DialogFlow platform was used. This platform is designed for integration into user applications and provides ready-made AI-based solutions from Google.

Figure 4 presents a schematic of the interaction between the components of the personal assistant, developed by the study’s author.

Based on the conducted analysis, an animated 3D model of the visual interface for the personal digital assistant Omega was developed for managing smart home systems. The system features voice command input, response delivery in both audio and text formats, command transmission to a server, processing via the DialogFlow platform, and execution by the smart home server.

The presented project won the regional stage of the JAS research competition and was awarded a second-degree diploma at the national stage of the competition in 2021.

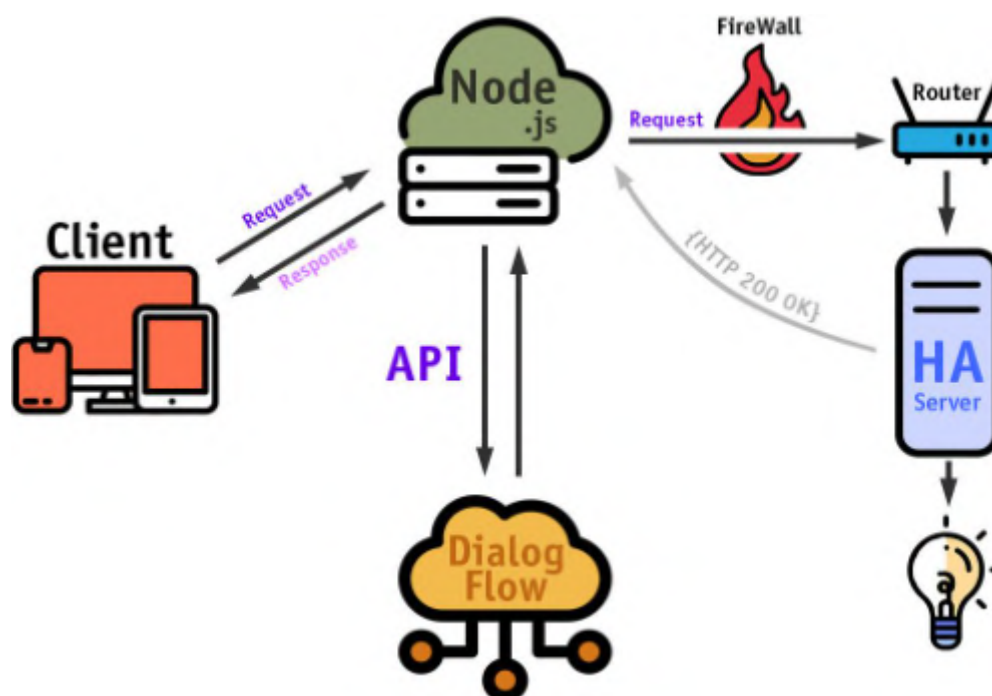


Figure 4. Diagram of the interaction between the personal assistant and the server.

The project became a significant milestone in the development of the student's cognitive competencies, particularly in the areas of critical, creative, analytical, and scientific thinking. The student demonstrated critical thinking by selecting appropriate tools and testing their effectiveness under practical conditions. During the project, the ability to independently identify optimal approaches was showcased, requiring analytical and creative skills. The use of scientific methods to achieve results highlights a high level of scientific thinking and research proficiency.

To implement AI-based projects, one can use publicly available pre-trained neural network models, train them on accessible datasets, and integrate them into custom software solutions.

In 2022, a project titled "Traffic Sign Recognition System" was developed. The object of the research is the process of traffic sign recognition. The subject of the research is traffic sign recognition systems and methods for implementing image classification tasks for traffic sign recognition. The research aimed to develop an application with a real-time traffic sign recognition system based on the analysis of image processing and classification tasks.

During the research, the methods for image processing and the application of neural networks to solve image classification tasks were explored [17, 18].

For image processing operations in the Trasifier project, the OpenCV library with computer vision algorithms was used, providing tools for image content processing. Object analysis in the images is performed using convolutional neural networks based on the EdLeNet architecture [19].

Figure 5 shows the interface of the Trasifier application in traffic sign recognition mode.

The presented project became the winner of the regional stage of the national competition of scientific research works (JAS) and received a 2nd-degree diploma at the national stage of the competition in 2022.

This project reflects not only the technical aspects of implementation but also contributes to the development of cognitive competencies, particularly the ability for analytical thinking, critical evaluation, and effective use of available technologies. The choice of a CNN for image classification is the result of a deep analysis of available technologies and a critical evaluation



Figure 5. Recognition mode screen.

of their effectiveness. The creative approach is demonstrated in the use of open datasets and the integration of various technologies to create a realistic application. Analytical skills are expressed through the selection of the optimal model for traffic sign recognition. Scientific thinking is demonstrated through the application of theoretical principles of machine learning and the use of appropriately selected tools to solve a practical problem. The project highlights the holistic development of the student's cognitive competencies, manifested in the effective application of knowledge and skills to solve practical tasks.

A similar approach to the development of AI systems, involving the integration of a pre-trained neural network model and training it on an open dataset, was used in the student's projects at the "Polit" Science Lyceum in 2023, titled "Computer Vision System for Waste Recognition", and in 2024, titled "Smart System for Underwater Navigation and Communication".

In these research projects, the student analyzed neural network models that are effective for solving object recognition tasks in combination with computer vision algorithms [20–23]. Neural network architectures were reviewed, and a suitable model that demonstrated high recognition accuracy was selected. The student proposed original approaches to applying object recognition systems in the infrastructure of "smart cities" and in the context of underwater operations. Tools for building computer vision systems based on neural networks and training them were explored. The implemented computer vision systems can recognize objects in photos and videos, including in real-time, and can operate locally or in a cloud environment.

The GarbageEye project received a 2nd-degree diploma at the regional stage of the JAS competition in 2023 and a silver medal at the national stage of the Genius Olympiad for environmental projects.

Figure 6 shows the interface of the DiveGuard project in the modes of recognizing surrounding objects in the underwater environment in streaming video (on the left) and diver gestures for issuing commands, along with the system's response to the command with health status data (on the right).

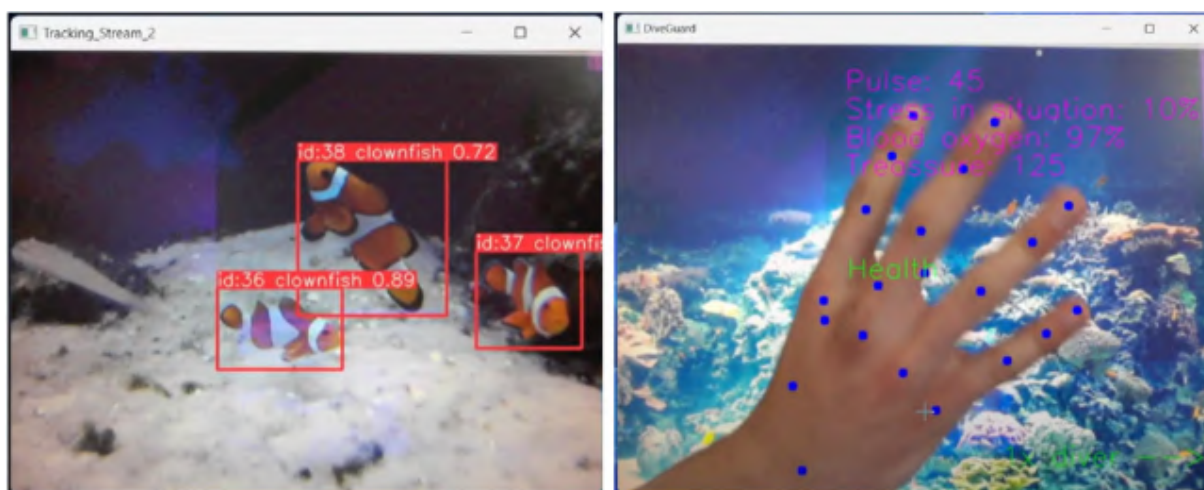


Figure 6. Recognition of objects and diver gestures in streaming video.

The DiveGuard project won a second-degree diploma at the national stage of the JAS competition in 2024, a gold medal at the national environmental project competition Genius Olympiad, and a silver medal at the international GENIUS Olympiad (2024, Rochester, USA). The student became a member of the international JAS team and represented the project at the Mostratec-Liberato 2024 International Science and Technology Fair (2024, Brazil) and at the Kaohsiung International Invention and Design Exhibition KIDE (2024, Taiwan), where he received a bronze medal.

The GarbageEye and DiveGuard projects demonstrate a high level of cognitive competencies, particularly in the effective application of neural networks and computer vision algorithms to solve practical problems. The student's critical thinking is evident in the well-founded choice of neural network models, such as YOLOv7 and YOLOv8, based on a deep comparison of technologies and their ability to solve specific problems. The creative approach is demonstrated in the integration of innovative solutions for real-world applications, particularly in environmental monitoring and underwater navigation, showcasing the ability to adapt technologies. The student's analytical abilities are expressed through detailed analysis and fine-tuning of models to achieve high recognition accuracy, while scientific thinking is reflected in the effective use of open data and cloud technologies for testing algorithms. The development of real-time systems also highlights the student's research skills, which include working with large datasets and implementing algorithms for complex conditions. All these aspects collectively reflect the comprehensive development of cognitive competencies, contributing to the realization of innovative solutions in the fields of computer vision and machine learning. The student's personal progress, achieved over the years of working on projects, is reflected in the increasing complexity and sophistication of the projects, the effectiveness of their development, and the quality of their presentations.

The current stage of AI technology development has enabled another way for computer systems to access existing developments – sending queries to generative language models, such as ChatGPT, and processing the responses received. This approach was implemented by a student of the “Polit” Science Lyceum in 2024 in the research project titled “Voice Control in

Computer Systems”.

The research work focuses on the analysis of technologies for recognizing texts input via voice to control computer systems, aiming to create a personal voice assistant. The project investigates algorithms for converting voice input into text and generating speech from provided text. The mechanisms for using artificial intelligence elements to recognize the content of commands and their parameters were identified [24, 25]. A personal assistant, Nova, was developed, featuring voice command input and AI elements for controlling computer devices and interacting with users, based on the OpenAI library [26]. The Nova assistant could be especially useful for individuals with disabilities.

The presented project earned a third-degree diploma at the regional stage of the JAS research competition in 2024.

In the process of creating the project, the student demonstrated a high level of cognitive competencies, particularly critical thinking, which was evident in the careful selection of technologies for voice input and text generation. Creative thinking was manifested through the development of the Nova personal voice assistant, which combines voice input and text generation, enhancing the convenience and inclusive of use. Analytical abilities were displayed in the detailed analysis of the algorithms for converting voice to text and the reverse process of speech generation, ensuring a high level of system accuracy. Scientific thinking formed the foundation for implementing theoretical knowledge into a practical product by utilizing the OpenAI API. The project also demonstrates research skills, particularly in adapting modern language models to real user needs and creating an interactive voice control interface.

It can be expected that the technology of querying popular generative language models and processing the responses within student projects will become widespread in new student developments involving AI.

As part of this study, a comparative evaluation of the described projects was carried out in accordance with the criteria used in the competitive selection process of the JAS (figure 7).

The results of the analysis revealed a correlation between the level of systematic and comprehensive coverage of the research topic and the ability to think critically and formulate

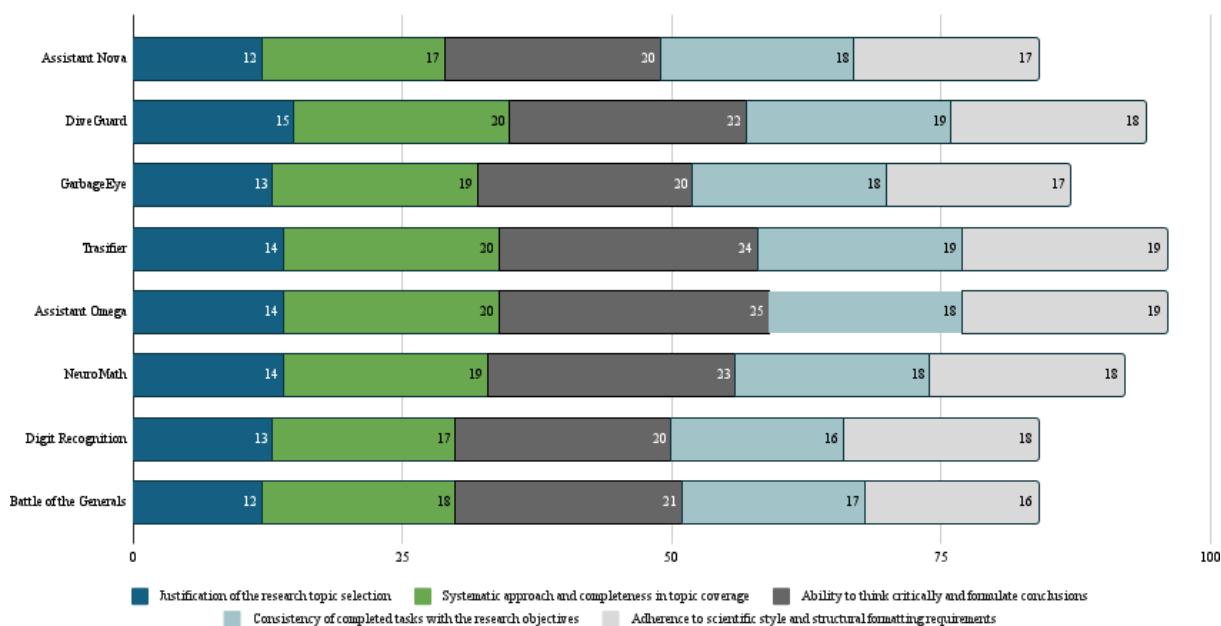


Figure 7. Evaluation of the components of students' research skills in projects according to relevant criteria.

well-grounded conclusions. This interdependence indicates that deeper engagement with the research topic directly contributes to the development of analytical thinking. The dynamics of the development of research competencies are particularly evident in the comparison of two successive projects by the same student (GarbageEye, 2023; DiveGuard, 2024), where an increase across all key indicators is observed. This is interpreted as evidence of the gradual formation and growing complexity of cognitive competence in the process of multi-stage project work.

In order to identify the potential impact of research-based project activities on the development of students' cognitive competence, an expert assessment was conducted. The assessment was based on rating scales that reflect behavioral indicators of three types of giftedness: intellectual, creative, and practical. The level of each type of giftedness was evaluated by experts both before and after the implementation of student projects. This made it possible to compare the dynamics of change and determine the potential impact of project activities on the development of the cognitive domain.

Figure 8 presents a comparative analysis of seven students' results across three forms of giftedness. A positive developmental trend is observed in all participants, with the average percentage increase in each category ranging from 6% to 13% compared to the initial level. The most significant improvement is noted in the intellectual component, indicating an enhancement of cognitive competence – specifically, the ability to pose questions, formulate hypotheses, justify decisions logically, and apply scientific thinking in novel situations.

Creative giftedness also showed growth, particularly among students capable of adapting complex algorithms to the specific conditions of a task and generating innovative solutions. Practical giftedness, assessed according to criteria such as the ability to apply technical skills rapidly, devise efficient everyday solutions, work with tangible objects, schematics, and resources, and navigate social situations, likewise demonstrated steady improvement. This indicates the

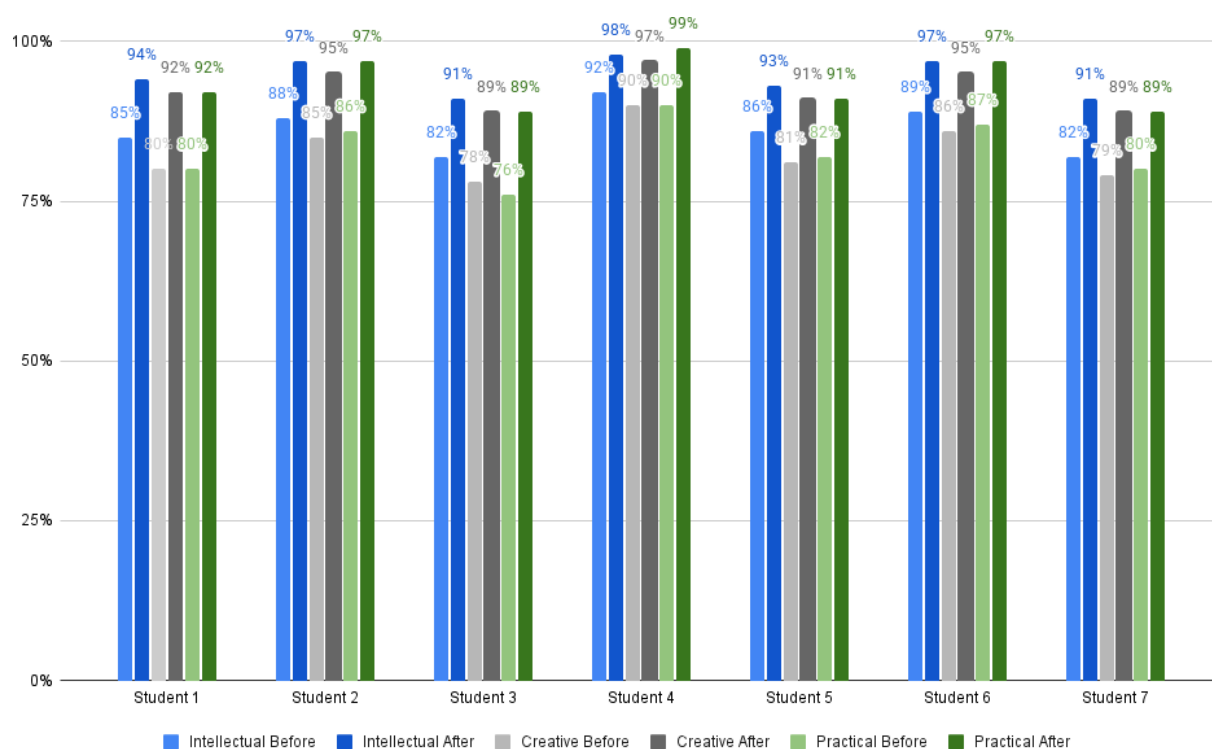


Figure 8. Dynamics of the development of students' intellectual, creative, and practical skills before and after project-based work.

development of functional thinking, spatial intelligence, resourcefulness in daily contexts, and the capacity to assess the feasibility of ideas under constrained conditions. Such results point to the practical integration of knowledge and skills acquired through research activities into broader, real-life contexts.

At the same time, the development of projects involving AI elements presents certain limitations. Legislation in many countries imposes age restrictions on the use of AI and requires parental consent for students to access AI resources. Therefore, involving parents in discussions regarding students' participation in such projects is essential.

Another challenge relates to the potential errors and biases of AI systems. During project development, the possibility of such inaccuracies is taken into account and documented accordingly.

Moreover, preparing competition-level projects is a lengthy process that demands students' ability to balance formal classroom and informal extracurricular activities. Participation in project development does not reduce academic expectations in regular school subjects. The uneven distribution of school workloads creates difficulties in maintaining consistent work on projects. Meanwhile, searching and processing sources, developing and testing software products, and preparing presentation materials for project defense may distract from fulfilling regular academic tasks. In this context, studies also confirm that the effective integration of AI into educational programs – taking into account age-specific features and individual learning trajectories – is critically important for ensuring the sustainable and purposeful development of student engagement in this field [27].

Thus, the widespread implementation of AI systems in various fields of human activity leads to an increase in student interest in this scientific direction and provides new mechanisms for developing their research projects, which, in turn, fosters cognitive competence and the ability to identify, analyze, and find solutions to new problems facing humanity. The integration of AI into object recognition systems, voice control, and computer vision has demonstrated a substantial improvement in functionality and data processing accuracy. This is confirmed by the success of student research projects.

4. Conclusions

AI is a powerful tool that contributes to the growing interest among gifted students in cutting-edge technologies. By integrating AI into student projects such as object recognition, voice control, and computer vision, young people are provided with opportunities to practically apply their knowledge and skills in real-world conditions, which stimulates their curiosity and motivation for further learning and research. Involvement in AI-related projects helps students develop critical thinking and analytical skills. For example, developing traffic sign recognition systems or computer vision systems for garbage detection requires detailed data analysis, selecting appropriate algorithms, and optimizing them, which promotes a deeper understanding of information processing and decision-making skills based on data.

AI-based projects foster scientific approaches and innovative thinking in young researchers. Students involved in the development of AI systems learn to formulate hypotheses, conduct experiments, analyze results, and present their findings. This not only enhances their technical skills but also develops their abilities for critical analysis and innovative thinking, while fostering an understanding of the nature and potential of AI technology management. The use of AI in educational projects allows students to see the practical application of theoretical knowledge. Projects such as real-time object recognition or voice control demonstrate how theoretical concepts can be applied to solve real-world problems. This increases the significance of learning, making it more engaging and aligned with current technological trends.

The implementation of AI technologies in projects also teaches students how to use neural networks and large data sets for learning, which is an important aspect of modern science

and technology. Knowledge about data processing methods, model training, and optimization becomes valuable for further scientific and professional development. AI integrates knowledge from various disciplines, such as computer science, mathematics, statistics, and engineering. Students participating in AI projects have the opportunity to develop interdisciplinary skills, which are crucial for solving complex problems in the modern world. Presenting AI-based projects and receiving awards at national and international competitions highlights the competitiveness of gifted youth on a global level. This recognition opens up new opportunities for further education and professional development.

Thus, all the presented projects demonstrate the importance of involving gifted students in extracurricular scientific research in the field of AI to develop their cognitive competence. These projects help form skills that will be valuable not only in education but also in their future professional careers.

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Creating of collaborative learning framework for Computer Science students training in the field of database design

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Abstract. The article considers the issue of the application of collaborative learning techniques in the process of professional training of IT specialists at higher education institutions. Based on the analysis of scientific publications, it is shown that the theoretical and applied aspects of collaborative learning are thoroughly developed. Therefore, it is necessary to adapt them to solve partial tasks of the educational process. For this purpose, we have designed a collaborative learning framework for Computer Science students training in the field of database design. The framework contains a description of stages of educational interaction between students and the teacher. The main stages of the collaborative learning framework for training in the field of database design: (1) obtaining of theoretical knowledge and formation of primary practical skills; (2) selection of the subject area; (3) conceptual database design; (4) logical database design; (5) physical database design; (6) presentation of results; (7) evaluation of results. The framework was implemented in the teaching of the bachelor course “Databases and Information Systems” at Bogdan Khmelnytsky Melitopol State Pedagogical University. 30 second-year students of the specialties Computer Science and Vocational Education (Digital Technologies) took part in the study. There were no statistically significant differences between the studied groups. At the same time, students who worked in teams gained experience in teamwork, awareness of its advantages and difficulties, and skills in peer learning, self-assessment, and peer assessment. The conducted empirical research has shown that the application of collaborative learning techniques has significant educational potential for developing IT students’ abilities to teamwork.

1. Introduction

Professional activity in the field of information technology involves active interaction with colleagues, managers, and clients. Well-developed soft skills can ensure effectiveness and reduce stress. Such skills should be developed during professional training [1], particularly in higher education institutions [2]. This can be facilitated through teaching methods and technologies that encourage active interaction among participants in the educational process.

The professional training of Computer Science students and the development of their hard and soft skills are examined in contemporary pedagogical research. Some aspects of this topic



are discussed in publications [3–9] and among others.

Collaborative learning is a powerful method for forming and developing skills, essential for teamwork. This approach involves the joint acquisition of knowledge, the development of individual skills, the socialization of the individual, and the formation of communication skills by combining efforts to solve educational tasks [10, p. 98-99].

Various forms of collaborative learning are effective due to their features: positive interdependence of participants in groups; individual responsibility of each for common results; heterogeneity of groups; shared leadership in groups; joint responsibility for each other; emphasis on tasks and their support; formation of social skills directly in the process of cooperation; the teacher observes and joins in when necessary; the group analyzes its effectiveness; appreciation of each person's skills and contribution; development of metacognitive skills; symmetry; joint distribution of work and tasks; strengthening intrinsic motivation [11, p. 259].

The use of collaborative learning in the process of studying Computer Science contributes to the formation of the ability to work effectively in a team, and improves the quality of the educational process by intensifying cognitive processes (when students explain the material to each other, ask questions or discuss, they usually make more mental efforts in studying the material), activates the exchange of experience, information, ideas, and enhances students' motivation (especially at the beginning of their studies) due to the social effect of integrating the individual into the team [12, p. 1].

The use of collaborative learning techniques is associated with certain difficulties. Educational cooperation is difficult to plan and organize since it is necessary to take into account the individual characteristics of students, group dynamics, group coordination, its features, and experience. Therefore, planning and controlling these processes requires significant time and resource expenditure, especially to coordinate group work, select and create materials, and manage social interaction. As a result, poor attention is paid to the structuring of teamwork, methodological support for students, reflection, and evaluation of teamwork [12, p. 1].

These and other difficulties lead to a contradiction: teachers recognize the importance of collaborative learning but do not use it systematically enough in compliance with methodological guidelines. This is noted by Schulz et al. [13].

Scientists examine various aspects of collaborative learning as an effective technology for training Computer Science students. Scientific works highlight such issues, as: computer support of collaborative learning [14–16]; assessment of students' educational achievements [17, 18]; formation of students' individual abilities [11, 19, 20]; management of the process of educational cooperation and support for students [21–23]; planning collaborative learning [12]; application of artificial intelligence for the organization and support of collaborative learning [24], etc.

Thus, the methodological fundamentals of collaborative learning are well developed, and research of their individual applied aspects continues.

An important component of the professional training of IT specialists in higher education institutions is the formation of competence in the field of database design, development, and use. This is objectively due to the fact that database technology is widely used to store information in small, medium, large, or corporate information systems [25, p. 2681].

The formation of this competence in the process of training IT specialists in the Ukrainian higher education institutions is characterized by a number of problems, in particular: theoretical material is often difficult for students; performing practical tasks close to real industrial projects requires time and teamwork, as well as the willingness and ability to explore different subject areas; currently, the IT industry uses various data storage models and database management systems (DBMS), and therefore the problem of a well-founded selection of training content arises.

Ukrainian scientists examine various aspects of teaching databases, in particular: the methodology for teaching the theory of normalization of relational databases [26], teaching database design [27–29], teaching non-relational databases [30] etc. The works of foreign

researchers are also devoted to various problems of teaching databases, in particular: content, methods and means of teaching [25,31–33], using the project approach and working in teams [34], teaching the development and optimization of queries in databases [35,36], teaching database design [37], etc.

The results presented in these and other works can be adapted to the conditions of the Ukrainian higher education institutions, however, the task of finding ways to improve the educational process, taking into account the changes taking place in the industry and the conditions of specific HEIs, in particular, relocated ones that work only in remote mode, remains relevant.

The aim of the study is to develop a collaborative learning framework for Computer Science students training in the field of database design based on the analysis of scientific sources, to conduct its pilot implementation, and to identify directions for its improvement.

2. Methodology

The research consisted of such main stages:

- 1) search and selection of scientific publications on collaborative learning and database training methods;
- 2) analysis of selected scientific publications;
- 3) development of a collaborative learning framework for Computer Science students training in the field of database design;
- 4) empirical study.

The following research methods were used: bibliometric analysis; analytical review of publications; systematization and generalization of information; modeling, pedagogical design, and empirical research methods were used. The VOSviewer software was used to build a map of the relationships of keywords that simultaneously occur in scientific publications. We relied on the articles on using of this tool [38–42].

3. Literature review

3.1. Bibliometric analysis

A search for scientific publications in the scientometric database Scopus was conducted using the key phrases “collaborative learning”, “higher education”, “computer science” and “database course”. Two queries were formed:

- TITLE-ABS-KEY (“collaborative learning” AND “higher education” AND “computer science”). This query found 69 publications, the first of which is dated 1997;
- TITLE-ABS-KEY (“database course” AND “higher education”). This query found 284 publications, the first of which is dated 2004.

The distribution of the publications by years (figure 1) shows that the scientific interest in the aspects we are studying fluctuates. The use of collaborative learning in Computer Science teaching in higher education institutions attracts stable attention. Interest in the problems of teaching databases in higher education institutions is gradually growing.

To construct a map of keyword relationships, the search queries were limited to the period from 2014 to 2024.

The query **TITLE-ABS-KEY (“database course” AND “higher education”) AND PUBYEAR > 2013 AND PUBYEAR < 2025** selected 228 publications. In this dataset, 1715 keywords were selected. When setting a minimum limit of 10 words (a keyword appears at least 10 times in the dataset), the number of keywords decreased to 21. These keywords were combined into 4 clusters (figure 2).

An interpretation of the formed clusters is given:

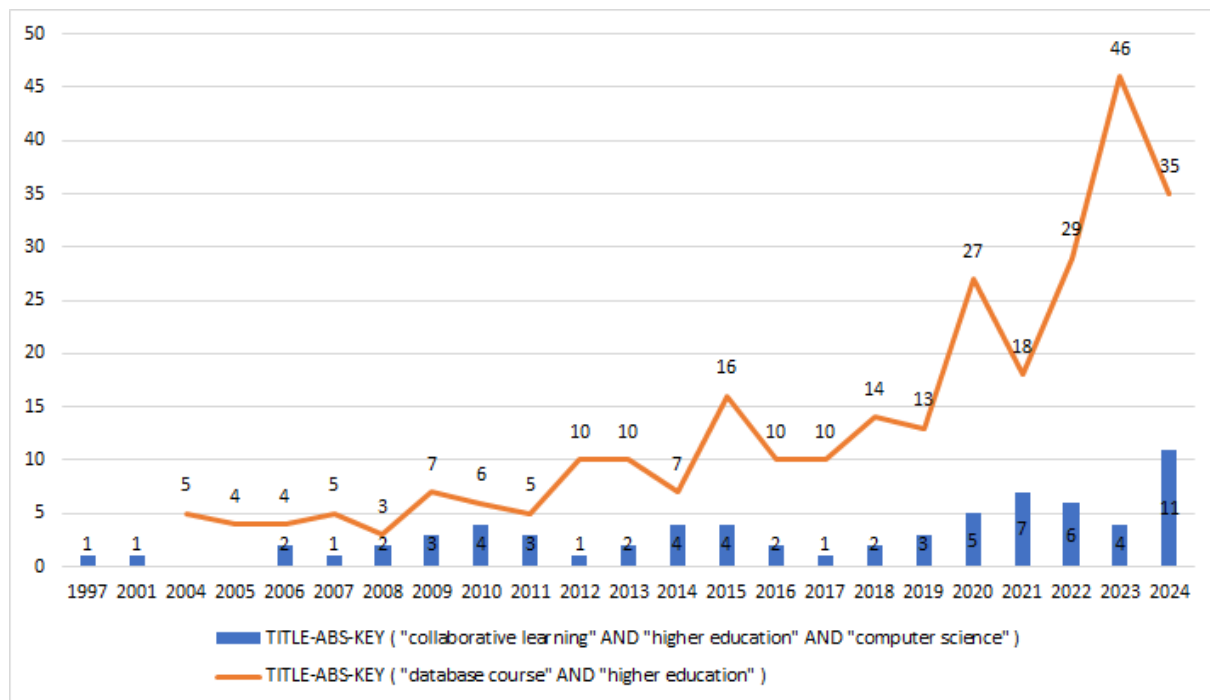


Figure 1. The distribution of the publications by years.

1. *The first cluster* aggregates 9 items, namely: data mining; education; education computing; engineering education; gamification; higher education; learning systems; student performance; students. These concepts relate to education in general, higher education, and teaching methods.
2. *The second cluster* aggregates 5 items, namely: automation; query languages; query processing; relational database. These concepts relate to database and query processing.
3. *The third cluster* aggregates 4 items, namely: curricula; database course; database systems; teaching. These concepts relate to database teaching.
4. *The fourth cluster* aggregates 3 items, namely: computer aided instruction; e-learning; surveys. These concepts relate to e-learning.

The query **TITLE-ABS-KEY (“collaborative learning” AND “higher education” AND “computer science”) AND PUBYEAR > 2013 AND PUBYEAR < 2025** resulted in 49 publications. In this dataset, 335 keywords were extracted. When setting a minimum of 5 words (a keyword appears at least 5 times in the dataset), the number of keywords decreased to 12. These keywords were grouped into 3 clusters (figure 3).

An interpretation of the formed clusters is given:

1. *The first cluster* aggregates 6 items, namely: collaborative learning; education computing; engineering education; higher education; students; teaching. These concepts relate to education in general, higher education, and teaching methods.
2. *The second cluster* aggregates 3 items, namely: computer programming; computer science; computer science education. These concepts relate to Computer Science teaching.
3. *The third cluster* aggregates 3 items, namely: computer aided instruction; e-learning; learning systems. These concepts relate to e-learning.

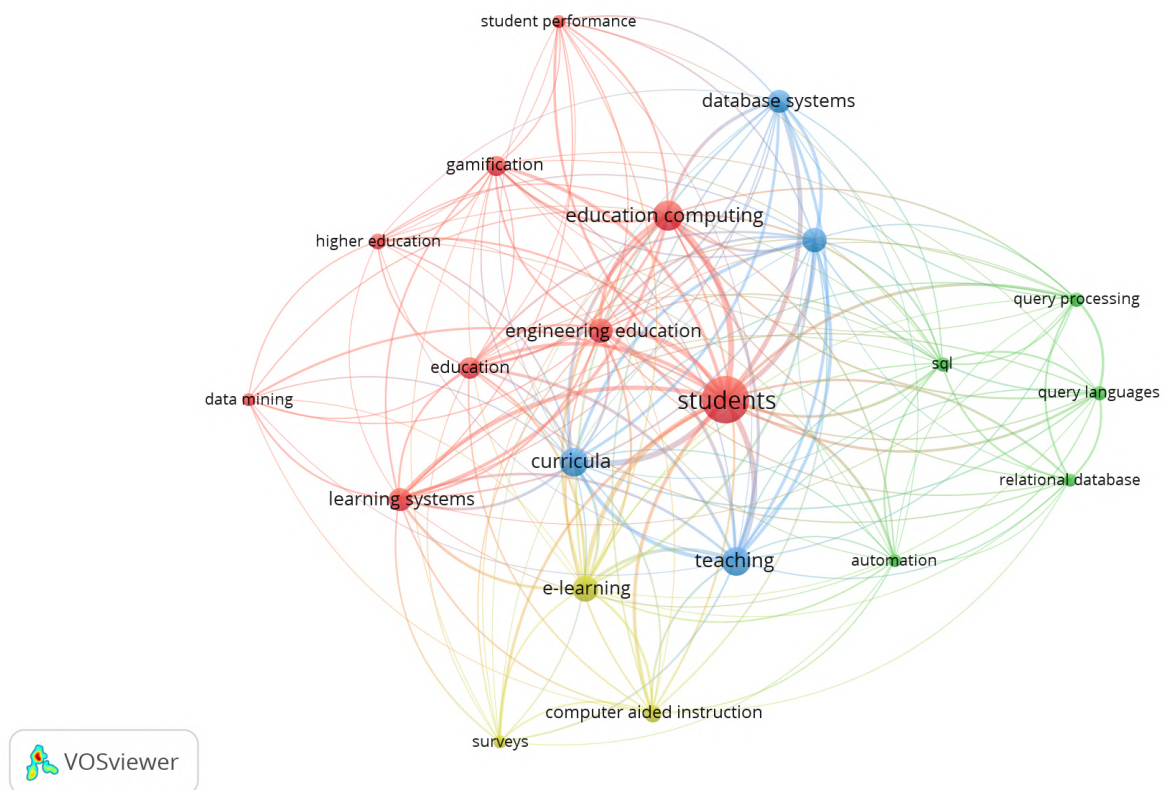


Figure 2. Map of keyword relationships in publications selected by the query TITLE-ABS-KEY (“database course” AND “higher education”) AND PUBYEAR > 2013 AND PUBYEAR < 2025.

3.2. Review of publications on the problem of collaborative learning

Planning of collaborative learning is a hard process. Hawlitschek et al. [12] focused on the development of a theoretical framework for its simplification and systematization. The authors distinguish two stages in the process of planning collaborative learning in Computer Science education:

1. Didactic analysis:
 - (a) analysis of the conditions of the educational environment and the learning context;
 - (b) analysis of students’ characteristics (cognitive, metacognitive, motivational, communication, etc.);
 - (c) analysis of learning objectives.
2. Educational design:
 - (a) *Structuring teamwork.* The level of structuring should be chosen based on the needs of the students and the learning objectives. A low level structuring can be used for informal discussions. A high level structuring is required for collaboration based on pre-defined scenarios (pair programming, scripted review work (students work individually, exchange feedback, and create group solutions), or group “puzzles” (each student performs an assigned role and corresponding tasks in the process of developing a joint product).
 - (b) *Group formation.* The size and composition of groups should be designed taking into account the learning objectives: small groups should be created for detailed feedback

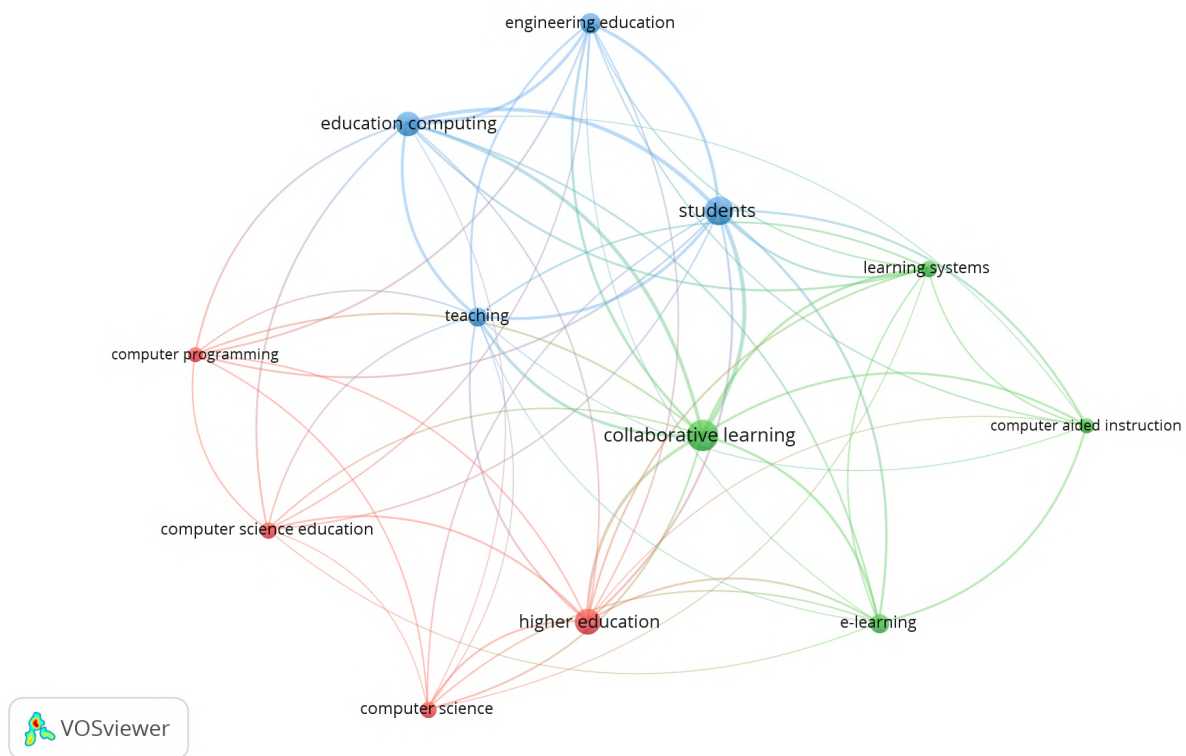


Figure 3. Map of keyword relationships in publications selected by the query TITLE-ABS-KEY (“collaborative learning” AND “higher education” AND “computer science”) AND PUBYEAR > 2013 AND PUBYEAR < 2025.

and guided coordination, large groups for modeling real industrial projects. The homogeneity or heterogeneity of the group composition also depends on the objectives. It should also be ensured that the tasks in the group are fairly distributed.

- (c) *Selection of teaching and assessment methods and tools.* The aim of this stage is to develop tasks, to plan modes of cooperation, to choose forms of assessment. Tasks for group work should promote cooperation, provide for individual contributions of each participant to the group result, and have a sufficient level of complexity to stimulate students without overloading them. To organize learning, it is advisable to combine synchronous and asynchronous modes of cooperation. It is necessary to plan the use of group and individual forms of assessment, in particular: assess group results, taking into account the contribution of each participant; conduct peer assessment to assess participation and the quality of cooperation; ensure transparency of assessment criteria.

The use of such a systematic approach will contribute to obtaining a clear plan for collaborative learning. However, even in the case of using this framework, planning and implementing educational cooperation of education seekers remains a laborious process. In view of this, research aimed at its automation is relevant. For example, Arroyo et al. [14] propose a methodological approach and a digital tool for modeling and supporting educational cooperation.

The teacher’s activities are important for effective collaborative learning: mentoring, providing instructions at the beginning and during the work of groups, providing feedback on the results of individual stages and work in general. This aspect is considered in [22, 23].

Lai [22] emphasizes the influence of conducting the group activities on the effectiveness of

project learning. He notes that the results of students' projects are often unsuccessful due to the low focus of discussions on the set goals and the lack of systematic monitoring of the project [22, p. 2278]. To overcome these problems, he proposes an approach to organizing group regulated learning, within which students can set learning goals, share tasks and adjust their learning progress.

According to this approach, at the beginning of the training, the teacher presents the course syllabus so that students understand the meaning of group regulation and learning objectives. Next, students define the goals of group learning based on their previous experience and record them on the learning platform. After that, they undergo individual training and collaborative project-based learning. In the process of individual training, students study the training materials and complete the tasks, also posting the results and providing access to them so that others can review them and provide feedback. In the next stage of collaborative project-based learning, students jointly complete the group task, provide access to the results of the group's work on the forum, and also review the progress of other groups. After completing the training, they move on to the evaluation stage, during which they provide and receive feedback on learning performance and project management. Based on this, students adjust the group regulation mode and update the learning objectives if necessary [22, p. 2283-2284].

The assessment students' academic achievements is one of the crucial aspects of collaborative learning. The grades that students receive based on the results of group work (which are usually the same scores) do not always reflect their real individual success, since the level of effort may be uneven and the contributions of each to the overall result may differ significantly. The lack of recognition of individual contributions to group work may cause students to have a negative perception of teamwork. On the other hand, taking into account the results of each will contribute to the formation of a sense of fairness, openness and readiness for cooperation [17, p. 10698].

To solve this problem, it is advisable to improve assessment policies, and to use digital technologies that help optimize the assessment and make it clear. For example, researchers from Portugal have developed the WebAVALIA system – a tool for self-assessment and peer assessment of students' work in groups that provides fair and unbiased individual results based on taking into account the opinions of group members about their own contribution and the contribution of their colleagues, helps teachers understand the level of agreement of students with the received grades [17, 18].

The Jigsaw classroom is a research-based cooperative learning technique developed in the 1970s by Elliot Aronson and his students at the University of Texas and the University of California [43].

To implement the Jigsaw classroom learning technique, it is necessary to follow 10 steps [43]:

1. Divide students into 5- or 6-person jigsaw groups. The groups should be diverse in terms of gender, ethnicity, race, and ability.
2. Appoint one student from each group as the leader.
3. Divide the day's lesson into 5-6 segments.
4. Assign each student to learn one segment. Make sure students have direct access only to their own segment.
5. Give students time to read over their segment at least twice and become familiar with it. There is no need for them to memorize it.
6. Form temporary "expert groups" by having one student from each jigsaw group join other students assigned to the same segment. Give students in these expert groups time to discuss the main points of their segment and to rehearse the presentations they will make to their jigsaw group.

7. Bring the students back into their jigsaw groups.
8. Ask each student to present her or his segment to the group. Encourage others in the group to ask questions for clarification.
9. Float from group to group, observing the process. If any group is having trouble, make an appropriate intervention.
10. At the end of the session, give a quiz on the material.

The experience of implementing the Jigsaw technique in hybrid learning is described in [44]. Ortega-Arranz et al. focused on studying the level of workload of teachers, taking into account the specifics of organizing collaborative learning in an online environment. According to the results of the study, it was found that teachers assess their workload as medium and high. Live group management, constant monitoring of group interaction, and solving technical problems require additional efforts.

An example of using collaborative learning techniques during laboratory classes for Computer Science students is given in [20]. A typical laboratory work involves completing some programming tasks, most of which are published in the e-learning system at the beginning of the week and can be completed at home. One or two more complex tasks are given to students during the laboratory session. Introducing elements of collaborative learning into traditional laboratory work allows students to discuss problems and difficulties with their classmates, encourages them to explain the work done clearly and concisely [20, p. 231].

O'Neill and Mooney present the following option for organizing collaborative work on programming tasks [20, p. 231-232]:

- 1) at the beginning of the group work session, students receive access to the programming task;
- 2) they are given 10 minutes to familiarize themselves with the task and write notes;
- 3) students are divided into groups of 4 and given 20 minutes to discuss and create high-quality pseudocode to solve the problem, they can also ask for help during the last 10 minutes if they have difficulties understanding the problem;
- 4) after the session, students fill out a questionnaire in which they describe their experience during the session, evaluate the usefulness of different stages for performing the algorithm, describe their previous experience and contribution to the discussion.

Standl et al. [16] examine the use of the gather.town platform for small group discussions in an online Master's degree in Computer Science. For group discussions, students form teams of up to six people at tables and complete tasks using a specific method presented in a lecture. During the discussions, the teacher visits the groups to answer students' questions. After the discussion, students take turns gathering around the group tables, where one of the group members presents the solution on a virtual whiteboard. In the course "Software Product Line Engineering", group discussion tasks are built around a cross-case example, where each task focuses on a different stage of the software product line engineering process. This allows students to save previous results on the whiteboard and continue the discussion in stable groups throughout the course [16, p. 90].

3.3. Review of publications on the problem of database training

Various aspects of teaching the course "Database Design and Processing" are described by Yefymenko [28, 29]. Yefymenko considers this course as part of the professional training of IT specialists and Computer Science teachers. He uses a traditional approach – a combination of lectures with laboratory work and independent work of students. In particular, when studying relational databases, students are offered typical tasks, for example: to develop a database

“Dean’s Office”, “Human Resources Department”, “Library”, “Travel Agency”, etc. [28, p. 116-117]. The course content includes the relational data model and DBMS, data mining, the basics of expert systems, NoSQL databases. However, in our opinion, it is advisable to study this material within the separate academic courses.

The formation of the ability to databases conceptual design is of great importance in the process of learning databases. Bulatetskaya et al. [27] note that for this purpose it is advisable to use competency tasks, the completion of which helps to form the ability to build ER models, assess their correctness and optimality, find and correct errors [27, p. 8]. They suggest to provide students with individual tasks for designing ER diagrams for real subject areas or for real enterprises. When formulating such tasks, it should be taken into account that students are not familiar with various subject areas, so it is necessary to provide their minimal description.

The problems of teaching database design and development are considered by Peinl [37]. He notes that the cost of correcting errors made in the early stages of program design often increases exponentially with the increase in the number of stages between detection and correction. Databases are an important part of almost any software system and correcting design errors in working software is quite expensive. In addition, such errors are often simply impossible to correct. In this regard, it is extremely important that the database project fully complies with the specification, and the relational schema correctly reflects the project [37, p. 29]. As he thinks, a database course should consist of at least three separate mandatory and/or elective academic disciplines. If students are offered only one academic course, he suggests teaching it on the basis of a systematic three-stage approach: 1) drawing up a description of the subject area, identifying limitations and redundancies, and refining the specification; 2) accurate translation of the rule-based specification into an equivalent relational schema; 3) implementation of the relational schema using SQL in a specific DBMS.

Sytnyk and Zinovieva [30] justify the need to study NoSQL databases in the process of professional training of bachelors in the specialty “Computer Science”. The authors note that traditionally in higher education institutions they study relational databases, which are the standard for organizing the storage and processing of structured data. However, technologies that require processing unstructured data are now being intensively developed. This task is solved, in particular, using NoSQL and NewSQL databases. In this regard, it is advisable to introduce the appropriate material into the content of professional training of bachelors in Computer Science [30, p. 255-256].

Iserte et al. [34] propose a methodological approach to database training. It involves a combination of the project method and teamwork: students are offered projects that are close to real ones, and separate teams are created to carry them out. It has been shown that this approach makes the learning process more attractive, since students find themselves in a working situation where a group of people has to solve a real problem. Due to various types of activities, schedules and teamwork, they form and develop subject competencies and soft skills (the ability to analyze and synthesize, solve problems, autonomous learning, critical thinking and leadership, etc.) [34, p. 224].

Barra et al. [31] present the experience of using web quests (escape room) in the process of teaching database. The quest is designed so that students can complete it in two hours at a convenient time during the last two weeks before the exam. The quest is created on the Escapp platform. The tasks in the quest are presented sequentially so that the solution of one opens the next. A quiz is used to help students. To get a hint, teams need to correctly answer at least four out of five random questions in a database quiz [31, p. 19].

Creating a quest room is a complex task and requires good design and integration with other course materials and activities. The time and effort spent by course staff to design and create educational quest rooms is significantly higher than for traditional practical classes in a computer laboratory. However, the positive impact on student engagement and learning efficiency makes

it worth the effort. In addition, the quest room can be reused in another course on the same topics or in successive editions of the same course [31, p. 24].

Zhang and Li [33] present a blended approach to teaching the course “Database Principle and Application”, based on a combination of classroom work with independent study of selected materials of Massive Open Online Courses (MOOCs). They consider the use of MOOCs as an additional teaching method to help students prepare for classes, revise the content after classes, speed up classroom work and develop students’ ability to learn independently. They offer a number of specific practices, including [33, p. 2031-2032]:

- *Preparation for teaching.* The course is divided into six parts: a general overview of databases; an overview of the relational model; the SQL language; database system development; database management systems; new database technologies. Each part is divided into several points. The teacher prepares as much information as possible, records a video, and develops several training exercises for each of them. The course outline, its plan, videos and exercises are uploaded to a specialized web platform.
- *Learning process.* It is necessary to determine the goal and ways to achieve it, upload course materials to the platform, organize student learning; then study the difficulties and key points in the classes, identify and eliminate shortcomings; provide timely feedback after the class. The specificity of the approach is that the teacher uploads plan, training video, presentations, extended materials, and practical tasks to the MOOC platform a week before the class. So that students can study independently. During the class, the teacher checks their achievements, in particular the exercises performed, and then gives targeted explanations.
- *The content of the first lesson.* The first lesson is an introduction to the course. Since students have individual psychological characteristics, the first lesson is especially important and its preparation requires special attention. During its conduct, it is necessary to reveal the following issues: what knowledge is needed to successfully study this course; how this course is related to other computer professional courses; course content; requirements for studying the course.

4. Research results

4.1. Collaborative learning framework for training in the field of database design

The theoretical basis of the framework is formed by the works of de Jesus and Silveira [11] and Hawlitschek et al. [12].

The framework is based on the following methodological approaches:

1. *Group work.* The teacher forms groups randomly or taking into account factors important in a particular case. The group independently chooses the subject area for database design and organizes its activities. The teacher monitors whether students adhere to the principles of activity, distribution of leadership and responsibility for the overall result.
2. *Jigsaw technique* [45]. The teacher uses it to theoretically prepare students for tasks. Students consolidate and deepen their basic knowledge of conceptual, logical and physical database design. To organize group interaction using this technique, the approach given by Ortega-Arranz et al. [44] was adapted.
3. *Peer learning.* Students who are experts in specific aspects of database design explain the learning material and provide necessary assistance to other group members in the process of completing tasks.
4. *Self-assessment and peer assessment.* At the end of the work, students evaluate their own results, the results of the work of other groups, and the contribution of each to the overall result of the group, using specified criteria.

The three-phase jigsaw implemented in this study is as follows:

1. *Individual phase.* Teacher assigns randomly one database design level (conceptual, logical or physical) to each student. Students must revise educational content and read the documentation. This phase is completed as homework within approximately 2–3 hours.
2. *Expert phase.* Students are grouped with other experts on the same database design level. They discuss some complex aspects and strengthen their knowledge. This phase goes on for one 2-hour class session.
3. *Jigsaw phase.* Teacher creates randomly groups from three students. Each of them is expert on the one database design level. Students must explain to the other group members their knowledge. This phase also goes on for one 2-hour class session.

The main stages of the collaborative learning framework for training in the field of database design: (1) obtaining of theoretical knowledge and formation of primary practical skills; (2) selection of the subject area; (3) conceptual database design; (4) logical database design; (5) physical database design; (6) presentation of results; (7) evaluation of results.

The author's framework is visualized by the flowchart (figure 4).

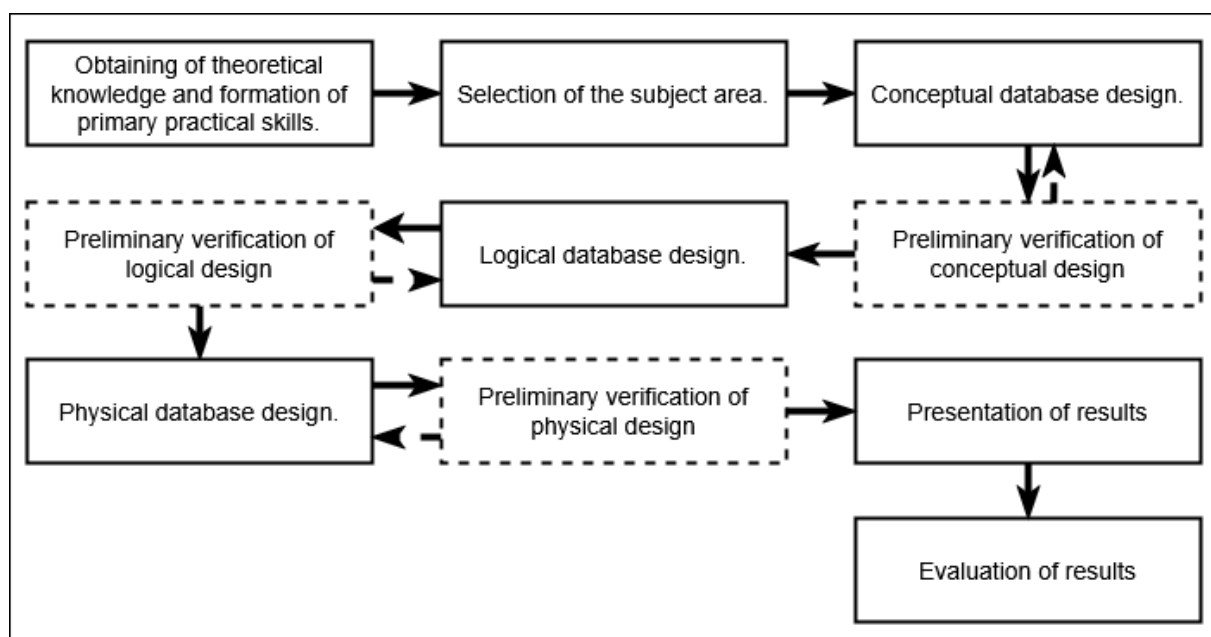


Figure 4. The collaborative learning framework flowchart.

The responsibilities of the teacher and the students at each stage of the framework:

1. Obtaining of theoretical knowledge and formation of primary practical skills.
 - (a) Students' responsibilities:
 - understand the theoretical foundations of database functioning;
 - acquire knowledge and initial skills in conceptual, logical, and physical database design;
 - prepare for practical tasks.
 - (b) Teachers' responsibilities:
 - explain the theoretical foundations of database design;

- prepare expert students and create opportunities for peer learning using the Jigsaw technique;
 - form groups of 3 students each. Each student is an expert in one level of design.
2. Selection of the subject area.
 - (a) Students' responsibilities:
 - suggest ideas for subject areas based on analysis of own experience;
 - choose a subject area.
 - (b) Teachers' responsibilities:
 - provide examples of subject areas;
 - help students formulate ideas for subject areas based on their experiences;
 - make sure that all group members have made suggestions and participated in the discussion;
 - mediate conflicts;
 - agree and record students' choices;
 - introduce students to the assessment procedure and criteria.
 3. Conceptual database design.
 - (a) Students' responsibilities:
 - develop a conceptual design of the database;
 - provide the result for preliminary verification to the teacher.
 - (b) Teachers' responsibilities:
 - involve all group members in the work;
 - mediate conflicts;
 - provide necessary assistance and explanations in case of problems;
 - check the result of the work.
 4. Logical database design.
 - (a) Students' responsibilities:
 - develop a logical design of the database;
 - provide the result for preliminary verification to the teacher.
 - (b) Teachers' responsibilities:
 - same as the previous step.
 5. Physical database design.
 - (a) Students' responsibilities:
 - develop a physical design of the database;
 - provide the result for preliminary verification to the teacher.
 - (b) Teachers' responsibilities:
 - same as the previous step.
 6. Presentation of results.
 - (a) Students' responsibilities:
 - prepare a report on the results of the work;
 - present the database project at the final meeting.
 - (b) Teachers' responsibilities:
 - introduce students to ways to prepare for presenting results;
 - organize a final meeting;
 - give students the opportunity to express themselves freely;
 - involve students in discussion.
 7. Evaluation of results.
 - (a) Students' responsibilities:
 - evaluate the result of your work;

- evaluate your contribution to the group's result;
 - evaluate the results of the work of other groups;
 - characterize your attitude towards group work on database design.
- (b) Teachers' responsibilities:
- determine the final assessment of the work of each group and each student;
 - summarize the results obtained;
 - give feedback to students.

To determine the final students grades, it is advisable to use three techniques in a complex: teacher assessment, self-assessment and peer assessment.

Assessment algorithm:

1. At the final stage, it is necessary to evaluate the finished database projects in points. The assessment is carried out by the teacher, the working group (self-assessment), other groups (peer assessment). Since the peer assessment is carried out by all groups, its result is calculated as the average mean of the points given by all evaluators.
2. To determine the overall score for the project, the equation is used:

$$FGP = k1 * taG + k2 * saG + k3 * paG \quad (1)$$

where FGP – overall project score; taG – teacher assessment grade; saG – self-assessment grade; paG – peer assessment grade; $k1, k2, k3$ – weighting factors of teacher assessment grade, self-assessment grade, and peer assessment grade respectively.

3. The next stage is the calculation of individual student grades. There are two possible options: each student receives a final score for the project; when determining the grade, the student's contribution to the overall work is taken into account.

To determine this contribution, teacher assessment, self-assessment and peer assessment are also used. The contribution is evaluated on a scale from 0 to 1. The equation used to calculate the student's final score is:

$$FGS = d1 * taC + d2 * saC + d3 * paC + d4 * FGP \quad (2)$$

where FGS – final student's grade; taC – teacher assessment of student's contribution; saC – self-assessment of student's contribution; paC – peer assessment of student's contribution; $d1, d2, d3, d4$ – weighting factors of teacher assessment grade, self-assessment grade, peer assessment grade, and overall project score respectively.

The maximum number of points for completing the work, as well as the weighting factors $k1, k2, k3, d1, d2, d3, d4$ is determined by the teacher.

Teacher's preparation for implementing collaborative learning technique in database design training should include the following steps:

1. Determine the amount of training material sufficient to form a theoretical and practical basis for group work. Prepare the necessary methodological materials.
2. Determine the number of hours of classroom and independent work for each stage.
3. Determine the criteria for evaluating the results of group work.
4. Select software tools and online environments for group work. The choice of training tools depends on the specifics of the educational program. The following tools can be used:
 - *Tools for creating and administering databases.* For example, for the MySQL DBMS these can be phpMyAdmin or MySQL Workbench. You can also use a low-code application platform for creating custom database-driven applications Caspio.

- *Services for group work:* an instant messaging and VoIP social platform Discord; a team collaboration application Microsoft Teams; an online learning platform Engageli; video conferencing service Zoom; a kanban-style, list-making web-application Trello; virtual board Padlet.

4.2. Empirical study

The proposed framework was implemented during the teaching of the mandatory bachelor course “Databases and Information Systems” at Bogdan Khmelnytsky Melitopol State Pedagogical University. 30 second-year students of the specialties Computer Science and Vocational Education (Digital Technologies) participated in the study. To perform database design tasks, 7 groups of 3 students each were created. The other 9 students worked independently.

Firstly, the students were familiarized with the theory and created a project of an educational database according to the teacher’s instructions. At the next stage, the teacher suggested options for subject areas and organized the process of selecting a topic for team and individual work. The working groups chose the following subject areas: accounting of employees; students’ academic performance; pet store; booking movie tickets; private enterprise providing plumbing services; bookstore; registration for a medical appointment.

To organize the work, the following tools were used: DBMS MS SQL Server; MS SQL Server Management Studio – software for configuring, managing, and administering all components within Microsoft SQL Server; a training course on the website of the MSPU Center for Distance Educational Technologies; an instant messaging and VoIP social platform Discord.

At the stage of evaluating the results, students evaluated the following parameters on a 20-point scale: the quality of their own team’s project, the quality of projects of all other teams, the effectiveness of their own activities, the effectiveness of the activities of other team members. The Google Forms service was used for this. The results obtained were processed by the teacher using spreadsheets.

To calculate the overall project score formula (1) was used. The following values were chosen for the weighting factors: $k1=0.6$, $k2=0.2$, $k3=0.2$. The team’s results are presented in table 1.

Table 1. Results of evaluation of students’ database projects.

Team	Teacher assessment	Self-assessment	Peer assessment	Overall score
Team 1	19	18	18	19
Team 2	10	16	15	12
Team 3	11	15	11	12
Team 4	13	16	13	14
Team 5	20	20	19	20
Team 6	17	18	18	17
Team 7	16	18	17	17

Based on the data presented, it can be concluded that the teacher had a more critical attitude towards the work than the students. The factors that caused this require additional study. However, we note that it is advisable to involve students in self-assessment and peer assessment, since these abilities are important for professional activity in the team.

The next step was to calculate the individual grades of the students using formula (2). The following values were chosen for the weighting factors: $d1=0.35$, $d2=0.15$, $d3=0.15$, $d4=0.35$. The results were grouped by levels of performance: low (0-13 points), medium (14-16 points), high (17-20 points). The distribution of students by levels is given in table 2 and figure 5.

For comparison, the results of students who worked in groups (collaborative learning) and individually (individual learning) are shown.

Table 2. The distribution of individual students' grades by levels of performance.

	Low level		Middle level		High level		Total
	students	%	students	%	students	%	
Collaborative learning	4	19.0	5	23.8	12	57.1	21
Individual learning	2	22.2	6	66.7	1	11.1	9

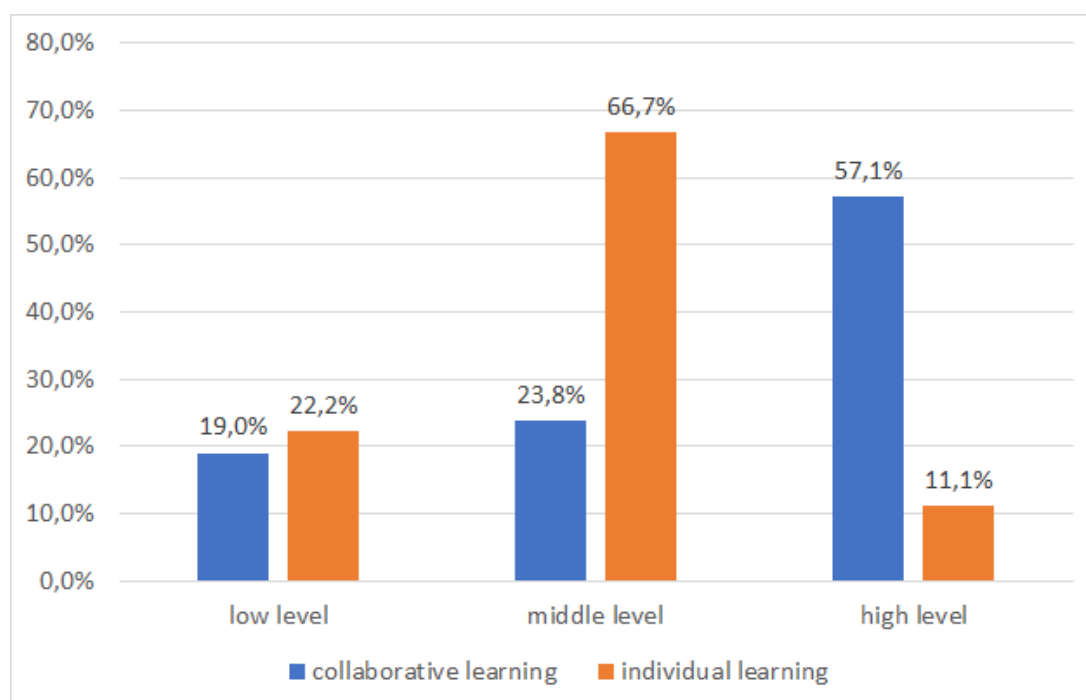


Figure 5. The distribution of individual students' grades by levels of performance.

Based on the data (table 2), it can be assumed that students who worked in groups completed better quality projects and received higher grades. However, testing the hypothesis of the presence of differences between the two samples using the Mann-Whitney U Test [46] showed that there were no statistically significant differences between the studied groups. That is, the results of students who completed projects individually and in teams do not differ. The factors that led to this result require further research. At the same time, students who worked in teams gained experience in teamwork, awareness of its advantages and difficulties, and skills in peer learning, self-assessment, and peer assessment.

After completing the project activity, students rated their level of satisfaction with collaborative learning using Likert scales [47, 48]:

- Are you satisfied with the composition of your team? (4-point Likert scale);
- Are you satisfied with the organization of the team's work? (4-point Likert scale);
- Are you satisfied with the results of your team's work? (4-point Likert scale);

- My team's project was evaluated respectively. (6-point Likert scale);
- My contribution to the team's work was evaluated respectively. (6-point Likert scale);
- During the project, I gained teamwork skills. (6-point Likert scale);
- During the project, I gained self-assessment and peer-assessment skills. (6-point Likert scale).

The results of the student evaluation are presented in figure 6 and figure 7. In general, it can be concluded that most students are satisfied with the teamwork, the results and the experience.

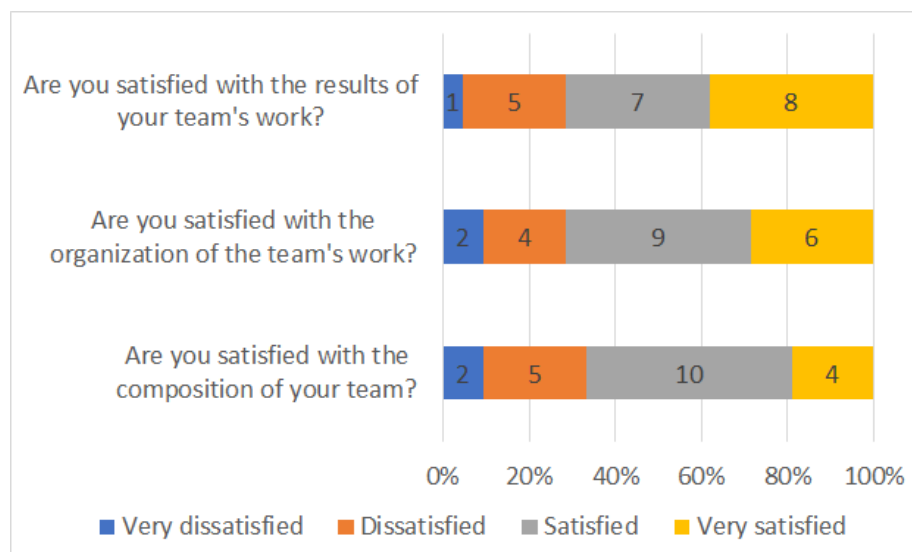


Figure 6. The level of student satisfaction with the process and outcomes of collaborative learning.

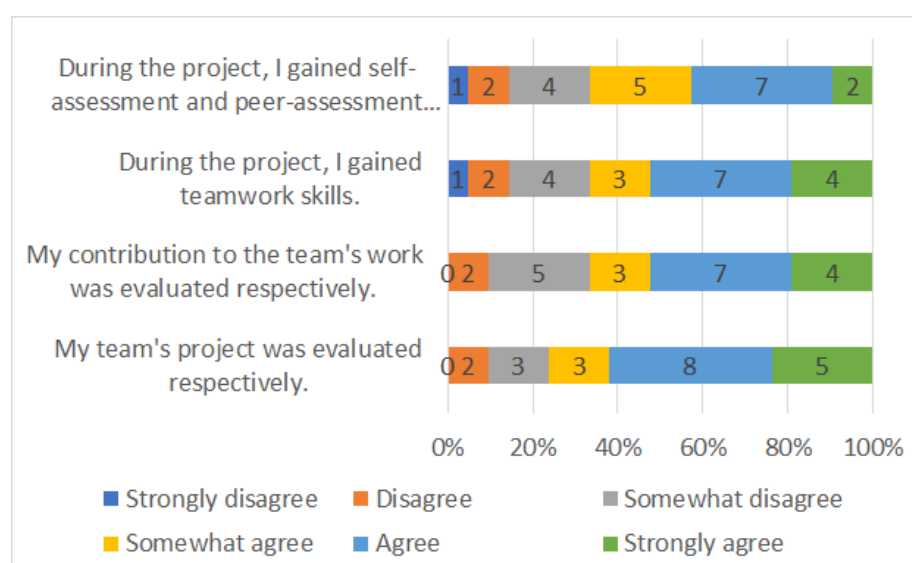


Figure 7. Students' attitude towards the outcomes of collaborative learning.

Based on the results obtained, it can be concluded that the framework needs improvement in the following areas: improving methods of organizing and controlling students' teamwork; developing convenient tools for self-assessment and mutual evaluation of teamwork results.

5. Conclusion

Professional training of IT specialists at higher education institutions includes the formation of their hard-skills and soft-skills. In particular, the topical task is to form students' abilities to design relational databases as well as to develop the abilities to teamwork, to self-assessment and peer assessment. To solve this problem, we have designed a collaborative learning framework for Computer Science students training in the field of database design.

The framework is based on the following methodological approaches: group work; Jigsaw technique; peer learning; self-assessment and peer assessment. The main stages of the framework are: (1) obtaining of theoretical knowledge and formation of primary practical skills; (2) selection of the subject area; (3) conceptual database design; (4) logical database design; (5) physical database design; (6) presentation of results; (7) evaluation of results. Teacher and students share responsibilities on each stage. To determine the final students grades, it is advisable to use three techniques in a complex: teacher assessment, self-assessment and peer assessment. Teacher's preparation for implementing collaborative learning technique in database design training should include the following steps: to determine the amount of training material sufficient to form a theoretical and practical basis for group work; to determine the number of hours of classroom and independent work for each stage; to determine the criteria for evaluating the results of group work; to select software tools and online environments for group work.

The framework was implemented in the teaching of the bachelor course "Databases and Information Systems" at Bogdan Khmelnytsky Melitopol State Pedagogical University. 30 second-year students of the specialties Computer Science and Vocational Education (Digital Technologies) took part in the study. The main result of the work was the formation of teamwork skills among students. At the same time, shortcomings of the framework were identified that need to be overcome.

The research results have the following limitations: (1) the developed collaborative learning framework is aimed at developing database design competencies, but the database professional training curriculum covers significantly more content; (2) the framework was implemented within one training course in one academic group of students, i.e. the conclusions obtained cannot yet be extended to all higher education institutions.

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Computational and algorithmic explorations of polygonal numbers: their role in computer science education

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Abstract. The challenges of computer science university education in terms of the students' unsufficient awareness of the value of mathematical knowledge and algorithmic thinking for their professional development are discussed in the paper. It is pointed out that significant cognitive facilities of mathematics as a science and as a powerful tool for explorations are applied insufficiently and too abstractly in university training, which does not allow the students to appreciate its great potential for them as future computer scientists. In this connection, exploration activity in the field of polygonal numbers is offered as a sample of integration of algebra, geometry and computation that brightly demonstrates cognitive power of mathematics and its application to real-life problems. The said exploration activity is based on the investigation of various properties of polygonal numbers along with elaboration of proper didactic and computer tools to make students involved in their own investigations of these numbers' characteristics. In accordance with its goals, the paper highlights author's obtained relations among flat polygonal numbers and explorations of their properties as algebraic systems which makes a theoretical framework for the work. Based on this framework, the proper computer models are developed and necessary didactic support for the students' engagement into computational and algorithmic explorations are elaborated and presented. Finally, there were investigated the benefits of the developed tools for the pre-service IT-specialists in terms of their awareness of math and algorithms value in their future professional activity. The levels of formation of the IT-specialists' awareness of mathematical knowledge value for their future career are determined. The survey and monitoring program were prepared and held which showed the changes in the distribution of the computer science students by the levels of the said awareness. The prospects of further research are outlined in terms of doing the empirical research for the verification of the impact of polygonal numbers explorational activity on the students' motivation to learn mathematics and algorithmization.

1. Introduction

Current IT industry turbulent development is accompanied with altering the levels and types of the problems that are getting urgent in this sphere. They are taking more and more sophisticated characters with significant mathematical framework, which causes renewing approaches to modern computer science education. It can be explained by the raising requirements for modern IT-specialists who are expected to demonstrate and implement mathematical, algorithmic and computational thinking which nowadays is considered to be essential basis for development of intelligence consuming software.



According to the guidelines that shape and represent contemporary paradigms in computer science education [3,7,8,16], computing knowledge domain is characterized as a family of subject areas (not an isolated domain) integrating some fundamental and applied branches which go on their evolution and interpenetration. Thus, computer science university education must respond to these tendencies cultivating the students' deep mathematical knowledge along with the skills of computational and algorithmic thinking. In accordance with studies, it will provide young professionals with abilities to comprehend complex real-life problems, to formalize them, build proper mathematical models, and finally find out efficient solutions grasped by a human and a machine as well [2,8,12,16].

Along with these growing demands to the new generation of IT-specialists, it must be emphasized that the current tutoring evidence and recent studies testify that computer science university education is facing the challenges of the students' low awareness of the value of mathematical knowledge and algorithmic thinking for their professional development [10–14]. Significant cognitive facilities of mathematics as a science and as a powerful tool for explorations are applied insufficiently and in too abstract way in university training, which does not allow the students to appreciate its great potential for them as future computer scientists. Algorithms mastering is also underestimated by the students, which prevents shaping their computational thinking that embraces algorithm developing along with decomposition, pattern recognition and abstraction [8].

Thus, it is relevant to apply computer modeling and algorithmization, to elaborate proper didactic mechanisms, and encourage IT-students to look at mathematical concepts as at objects of exploration demonstrating them computational value of mathematics, contributing to their mathematical outlook, and boosting their algorithmic thinking.

Searching proper mathematical concepts for exploration, involving students' math knowledge, computer modeling skills and algorithms building abilities, we were attracted by the phenomenon of polygonal numbers which can be considered as a sample of integration of algebra, geometry and computation that brightly demonstrates cognitive power of mathematics and its application to real life.

Polygonal numbers can be seen in real life everywhere: spider's web, honeycombs, topology of a network, eggs packed into a box are common examples of polygonal numbers of various angularity. On the other hand, a mathematical notion of polygonal numbers dated long before our era as a result of composition of the natural numbers' series made from the sums of arithmetic sequences. Under ancient times, these numbers' rows got also a geometrical interpretation: there were considered as sequences of regular polygons composed of stones, beans or just dots [9,15]. Among early researchers of polygonal (figurate) numbers there were Greek mathematician Hypsicles of Alexandria (II century before AD), Diophantus of Alexandria (III century, AD), Nicomachus of Gerasa (I century, AD) who obtained some relations between the numbers of different angularity. Later on, essential dependencies among natural and polygonal numbers were explored by famous mathematicians Pierre de Fermat (1601-1665), Leonhard Euler (1707-1783), and Augustin Louis Cauchy (1789-1857). Thus, the interest of researchers in polygonal numbers has a long history.

At the same time, the examination of resources on the topic uncovered that numerous intriguing relations among flat polygonal numbers have not been thoroughly investigated. Additionally, some established dependencies can be expanded and validated using contemporary mathematical techniques and computer modeling. Conversely, polygonal numbers, as a mathematical concept, evidently possess substantial educational significance: they enable STEM-students to comprehend the connection between the geometric and algebraic nature of numbers, to follow the continuity of geometric, algebraic and computational methods in mathematics, and to realize the application of abstract concepts to the solving of practical problems.

Thus, the exploration of various properties of polygonal numbers along with elaboration of proper didactic and computer tools to make students involved in their own investigations of these numbers' characteristics looks relevant and urgent for contemporary computer science education.

2. Purpose of the work

Coming from the said factors, the paper concentrates on the main objectives: (1) to highlight author's obtained relations among flat polygonal numbers and explorations of their properties as algebraic systems; (2) to develop proper computer models and elaborate necessary didactic support for the students' engagement into computational and algorithmic explorations; (3) investigate the benefits of the developed tools for the pre-service IT-specialists in terms of their awareness of math and algorithms value in their future professional activity.

3. Theoretical framework

The theoretical background of the work is made by the fundamentals of polygonal numbers theory and core author's results in this area presented in our previous works. Besides, there were used basics of GeoGebra applications to computer modeling [4]. There were also applied the theoretical issues of pedagogical diagnostics of the students' awareness of mathematical knowledge value and its dynamics in the progress of the students' vocational training enhanced with our didactic support in terms of polygonal numbers' explorations.

According to studies [9, 15], a number is defined as a K -angular, if it is one of the sums of the members of the arithmetic progression with the first member equals 1 and the difference $d = K - 2$. All numbers of different angularity can be presented as an infinite chart with the formula of the n -th index of the series of numbers of K -angularity (figure 1).

D	Polygon	Numbers						General member
		S_1	S_2	S_3	S_4	S_5	...	
1	Triangle	1	3	6	10	15	...	$\frac{n(n+1)}{2}$
2	Quadrate	1	4	9	16	25	...	n^2
3	Pentagon	1	5	12	22	35	...	$\frac{n(3n-1)}{2}$
4	Hexagon	1	6	15	28	45	...	$n(2n-1)$
...	...	...	...	...	...	...	...	...
D	...	1	$2+d$	$3+3d$	$4+6d$	$5+10d$	...	$\frac{n(dn-(d-2))}{2}$

Figure 1. Infinite chart of the polygonal numbers of different angularity.

Thus, the common formula of K -angular number with index n is [15]:

$$K_n = \frac{n[dn - (d - 2)]}{2} \quad (1)$$

The said definition is considered to be an algebraic one. It can be interpreted in geometric form demonstrating the geometric sense of the sums as a growing amount of dots on the sides of regular similar polygons. In figure 2 the four first triangular ($\mathfrak{3}_1, \mathfrak{3}_2, \mathfrak{3}_3, \mathfrak{3}_4$) and quadratic ($\mathfrak{4}_1, \mathfrak{4}_2, \mathfrak{4}_3, \mathfrak{4}_4$) are presented. Regular pentagons of other angularities are similarly obtained containing on their sides proper amount of points in accordance with K -angularity and index n .

In the progress of work, there were obtained some important relations among flat polygonal numbers which were also used to build author's computer models for polygonal numbers exploration and to develop a proper didactic support. In particular, we have obtained and

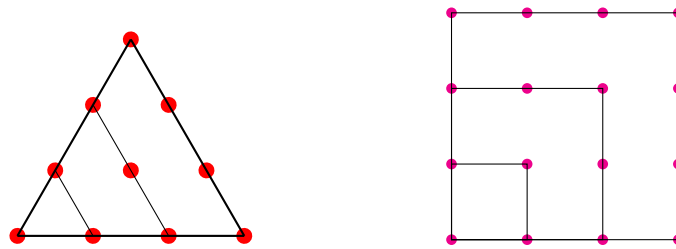


Figure 2. Triangular and quadratic numbers indexed 1-4.

algebraically proved a relation between n -th ($n > 2$) 5-angular number and 4-angular number indexed $(n-1)$:

$$5_n = 4_{n-1} + 4 + (n-2)(5+n)/2, \quad (2)$$

Some dependencies were obtained based the Diophantus's relation [9] for triangular and quadrate numbers. In particular, the relation between indexes n and m of triangular 3_n and quadrate 4_m numbers accordingly was found out for Diophantus's relation. Therefore, Diophantus's formula was generalized by us in such a way [6]:

$$8 \cdot 3_n + 1 = 4_m, \text{ where } m = 2n + 1 \quad (3)$$

Coming from algebraic transformations and geometrical sense, the formula (3) was generalized to the relation (4) linking the amount and indexes of triangular and square numbers:

$$4_p(8 \cdot 3_n + 1) = 4_{p(2n+1)} \quad (4)$$

Based on the relation (3), it was also discovered the regularity (5):

$$8 \cdot 3_n + 1 + 4 \cdot 3_n = 5_{(2n+1)} + n \quad (5)$$

that led us to the relation between triangular number (indexed n) and pentagon number (indexed $2n+1$):

$$12 \cdot 3_n + 1 - n = 5_{(2n+1)} \quad (6)$$

A geometrical interpretation of this algebraic fact was also provided by us in [6] giving explanations which are used for building didactic support for the students' explorations.

Besides these relations which are beneficial for understanding the polygonal numbers' properties, we have determined algebraic operations on the sets of polygonal numbers of different angularity based on the algebraic systems theory and the exploration of the polygonal numbers series.

In particular, in the progress of work the addition operation (7) and multiplication operation (8) are defined on a set of K -angular polygonal numbers ($K \geq 3$):

$$K_n \oplus K_m = K_n + K_m + (K-2)mn = K_{m+n}, \quad (7)$$

$$K_n \otimes K_m = 2K_n \cdot K_m \frac{dnm - (d-2)}{(dm - (d-2))(dn - (d-2))} = K_{nm}, \quad (8)$$

where $n, m \in N$ – indexes of K -angular numbers in a corresponding set.

Thus, it was concluded that the binary operations of addition and multiplication are invariant with respect to the angularity of numbers.

In addition, we also proved that the determined operations of addition and multiplication submit to commutative, associative and distributive laws. It was additionally obtained that a polygonal number indexed n equals a polygonal number indexed $n+1$.

There were also explored properties of polygonal numbers sets as algebraic systems with respect to the determined operations of addition and multiplication.

These mathematical results were presented in our previous works [4–6] in details and partially will be used below.

In the discussion section of the work, it will be also used the theoretical issues of pedagogical diagnostics of the students' awareness of mathematical knowledge value and its dynamics in the progress of the students' vocational training enhanced with our didactic support in terms of polygonal numbers explorations. Thus, there were distinguished three levels of formation of the trainees' awareness of mathematical knowledge value (here and below – Indicator): reproductive, productive, and creative levels. The levels are characterized as follows.

A trainee reveals the Indicator on the reproductive level, if he underestimates the value of mathematical knowledge; believes that computer science professional tasks can be solved without deep math background; demonstrates a situational desire to get familiar with the latest novelties in math and algorithmization.

A trainee reveals the Indicator on the productive level, if he admits the value of mathematical knowledge; believes that the efficient professional tasks solving in computer science requires deep math knowledge; periodically gets acquainted with the latest novelties in math and algorithmization, and understands the necessity to implement them in future vocational activity.

Finally, trainee reveals the Indicator on the creative level, if he has deep beliefs as for the value of mathematical knowledge; understands that the efficient professional tasks solving in computer science is impossible without profound math knowledge; is interested in the latest achievements in the field of math and algorithmization on the permanent basis and is ready to apply them in future vocational activity in creative way.

Based on the sources analysis [1, 2, 11, 13], there were revealed some diagnostics instruments to measure the trainees' level of the Indicator formation: survey and monitoring. The questionnaire for the survey and the monitoring program were developed.

4. Results and discussion

Obtained mathematical results as for the dependencies between flat polygonal numbers and their algebraic properties made necessary theoretical background for this work. They were implemented for the creation of dynamic computer models and proper didactic support for the students' engagement into computational and algorithmic explorations.

The set of author's computer models of polygonal numbers of different angularity were built in GeoGebra software (figure 3). Work with models is encouraged by the chain of prepared heuristics which provoke students to manipulate with the models parameters and do independent explorations on polygonal numbers essence and formation of their series.

Besides the manipulations and analysis of ready-made models (built by the author [5,6]), the trainees also suggested so called constructive activity, when they had to design similar dynamic models themselves based on the algebraic and geometric essence of flat polygonal numbers. Here the students came up with the simple solution for algebraic calculation of the total amount of dots, and challenging task to locate proper amount of points in the certain shape of a regular polygon, to formalize and automatize such a location of points using GeoGebra tools (or to find out algorithmic solution for coding). The students also had to mind that the built polygons must be geometrically similar and be overlaid to contain a certain amount of dots. Thus, the trainees again came up with the task to find out a regularity and the way how to visualize this regularity using computer.

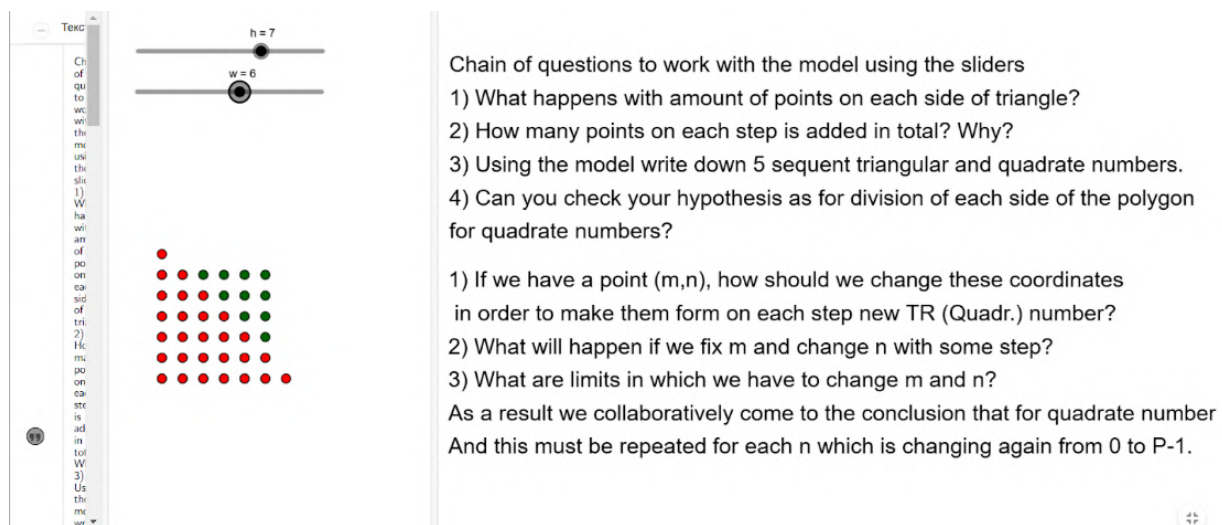


Figure 3. GeoGebra model for exploration of flat polygonal numbers. Episode of the students' explorations on polygonal numbers essence and formation of their series.

To facilitate the students' explorations and elicit from them fruitful solutions, we implemented a pre-teaching procedure encouraging students to answer the questions like these ones:

- (1) If there is a dot coordinated (m, n) , how to change these coordinates to make them compose on each new step next polygonal number in a sequence?
- (2) If we fix m and change n with some step, what will it cause?
- (3) What are the ranges of changing m and n ?

These and other questions provoke students' speculations helping them with challenging task of comprehending algebraic and geometric nature of the numbers. In addition, it is relevant to make students apply *Sequence* function as a built-in GeoGebra tool, as well as its nested variant [4]. It is also beneficial to emphasize the links with algorithms and coding (repetition algorithm structure, loop operator): first elicit this analogy from trainees and then underline it.

Finally, after building the models for exploring the numbers of certain regularity, the students are encouraged to create a generalized model for polygonal numbers of any angularity which is linked with practical geometrical tasks of points dispositions on the plane. The generalized model building should be accompanied by special didactic support including the set of the following subtasks.

- (1) The task of desposing K points around the circle (K is the angularity of a polygonal number)
- (2) The problem of repetition of the list of the gor rotations due to the index of a polygonal number of K angularity.
- (3) The problem of division of each segment between two points on the certain amount of points in accordance with the index of a polygonal number.

As a result, trainees are elicited to implement the nested construction of sequences and lists elements, comprehend it using GeoGebra *Sequence* and *List* functions. In addition, the students are able to manipulate parameters of the built generalized model to verify theoretical regularities of polygonal numbers (figure 4).

The next stage of work was focused on the building by the students two universal spreadsheets (in MS Excel, for instance) to verify the action of binary algebraic operations of addition and

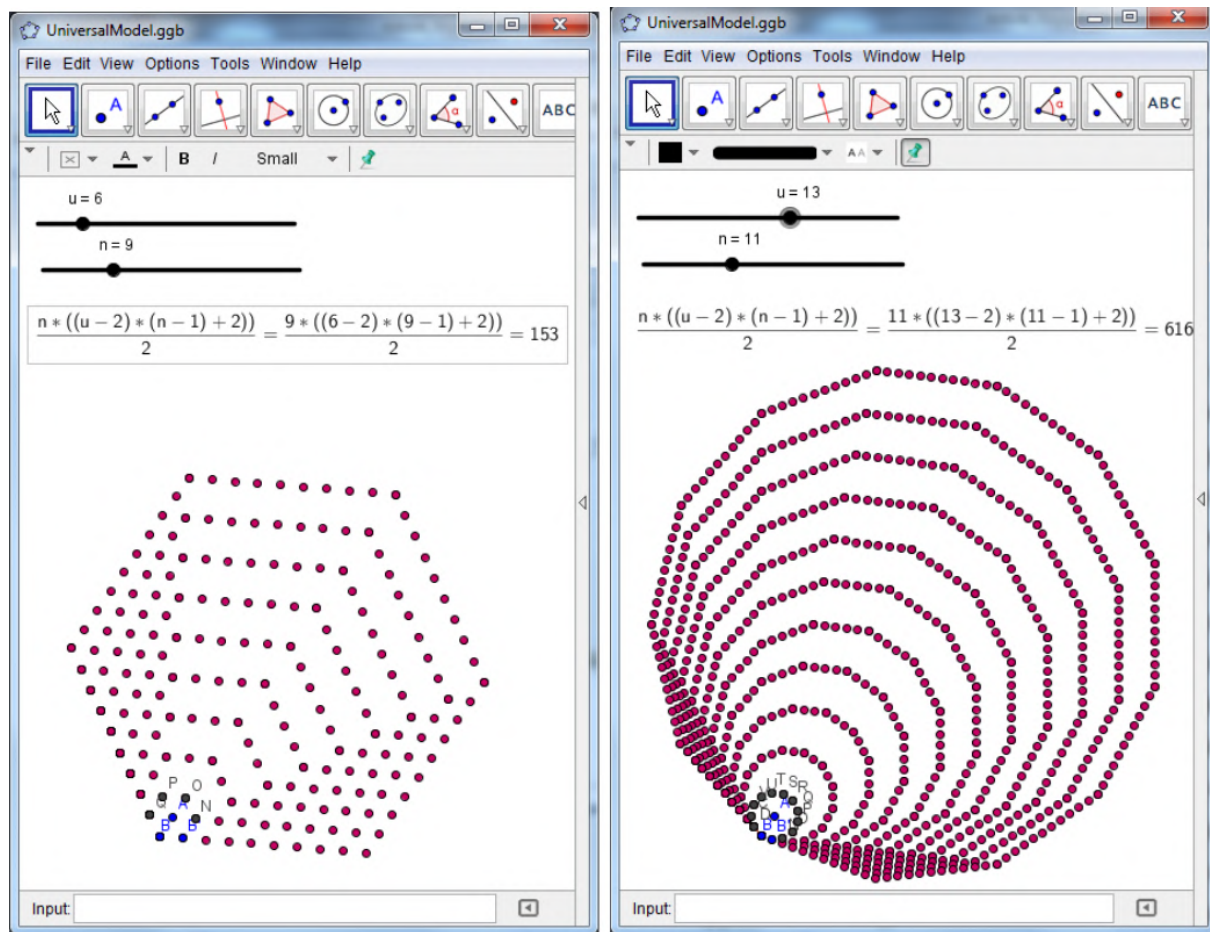


Figure 4. Episodes of students' work in GeoGebra with their own universal dynamic model for polygonal numbers of any angularity.

multiplication on the sets of polygonal numbers of different angularity determined in theoretical framework above. After that it is relevant to involve students into the exploration of geometrical interpretation of the said algebraic operations.

There was also developed a set of tasks to enhance the IT- students' algorithmic thinking while integrating their mathematical knowledge of polygonal numbers. It was also designed necessary didactic support for their solving. Here are some algorithmic tasks which aim to combine algebra, geometry, and computation, providing a comprehensive exploration of the topic.

Task 1. Develop a program that calculates the n -th term of any K -angular number sequence. Use for calculation the common formula of K -angular number with index n . Core requirements include:

- the program should accept inputs K and n ,
- input validation to ensure $K \geq 1$ and $n \geq 1$
- output the n -th K -angular number.

Task 1 extension: allow the program to handle vectorized inputs, computing multiple terms for various polygonal sequences simultaneously.

Task 2. Create a graphical representation of the first n terms of a specified K -angular number sequence. Core requirements include:

- design a function that plots points corresponding to each term, arranging them to visually form the intended regular polygonal shapes,
- ensure the visualization dynamically adjusts for different values of K and n ,
- incorporate interactive elements, such as sliders, to modify K and n in real-time.

Task 2 extension: animate the construction process of each polygonal number to illustrate the geometric progression.

Task 3. Design an algorithm that detects if a given integer M is a polygonal number of certain angularity K . If M is a K -angular number, the algorithm should return its position n in the sequence. Core requirements include:

- derive the inverse formula to solve for n :
- implement the algorithm to check if n is a positive integer.
- validate the solution by recomputing M using n and comparing it to the original input.

The more creative algorithmic tasks included the problems of (1) analysis and identification of patterns in the differences between consecutive K -angular numbers; (2) exploring higher-order differences and their relationships to other mathematical sequences or structures; (3) comparing different algorithms for generating K -angular numbers in terms of time and space complexity.

Finally, the students were offered to work upon the practically significant projects. For instance, it was the creation of a game simulator for schoolchildren to recognize and compute polygonal numbers; cross-disciplinary exploration where students had to research and identify instances where polygonal numbers appear outside of pure mathematics. The selected cross-disciplinary explorations held by the students included: (1) the problem of finding maximum amount of equal figures located inside of certain shape and its derivations; (2) the problem of time rows smoothing based on polygonal numbers usage and its application to exploring funds markets indicators; (3) the task of disposition of cell connection towers; (4) modification of genetic algorithms using polygonal numbers.

Thus, it is predictable that the presented above dynamic computer modeling, exploations and algorithmic tasks focused on polygonal numbers investigations enhanced by the didactic support could have a positive impact on the IT-students in terms of their awareness of mathematical and algorithmic knowledge value for their future profession (Indicator). On purpose of revealing the impact of the said activity on the Indicator, there was conducted a survey and a monitoring program.

Our monitoring testified raising the students' motivation and tendency to comprehend the mathematical and algorithmic essence of the exploration object. We could also notice the growing of the students' attention to algorithms building in the progress of software creation.

In addition, there was held the survey aimed at revealing students' reflexion of their work upon the polygonal numbers explorations based on computer modeling and algorithmic tasks solving. The survey comprised the following questions and tasks:

- 1) how do you estimate your degree of attraction of math and algorithms knowledge in the progress of software development (according to the given scale)?
- 2) did you change your opinion on the value of math and algorithms knowledge for coding? In which way?
- 3) how do you evaluate your level of comprehension of math originality of the offered tasks for exploration (according to the given scale)?
- 4) what experience did you gain during the work upon the exploration tasks?
- 5) how important does this experience seem for your future career in computer science? and others.

The results of the survey allowed us to conclude the following.

75% of the trainees admitted that doing explorations with polygonal numbers in GeoGebra and via coding encouraged them to apply math knowledge in a more concentrated way. Over 60% of the trainees admitted changes in their understanding of the practical value of the math knowledge for the software developing. Finally, about 70% of the trainees said that such an activity provided them with precious experience of math-based investigations in practically significant tasks.

Besides, the held survey revealed the changes in the distribution of computer science students by the levels of their awareness of the mathematical knowledge value for their future career. Thus, the number of trainees who revealed reproductive level of the awareness decreased by 2%, the number of trainees who demonstrated productive level decreased by 4%, and the number of students who revealed creative level of the said indicator increased by 7%.

The obtained results of our monitoring and survey may be used as an initial data for the empirical research for the verification of the impact of polygonal numbers explorational activity on the students' motivation to learning mathematics and algorithmization, which makes a prospect of our research.

5. Conclusions

The challenges of computer science university education in terms of the students' insufficient awareness of the value of mathematical knowledge and algorithmic thinking for their professional development are discussed in the paper. It is pointed out that significant cognitive facilities of mathematics as a science and as a powerful tool for explorations are applied insufficiently and in too abstract way in university training, which does not allow the students to appreciate its great potential for them as future computer scientists. In this connection, it is offered the exploration activity in the field of polygonal numbers as a sample of integration of algebra, geometry and computation that brightly demonstrates cognitive power of mathematics and its application to real life. The said exploration activity is based on the investigation of various properties of polygonal numbers along with elaboration of proper didactic and computer tools to make students involved in their own investigations of these numbers' characteristics.

In accordance with its goals, the paper highlights author's obtained relations among flat polygonal numbers and explorations of their properties as algebraic systems which makes a theoretical framework for the work. Based on this framework, the proper computer models are developed and necessary didactic support for the students' engagement into computational and algorithmic explorations are elaborated and presented.

Finally, there were investigated the benefits of the developed tools for the pre-service IT-specialists in terms of their awareness of math and algorithms value in their future professional activity. The levels of formation of the IT-specialists' awareness of mathematical knowledge value for their future career are determined. The survey and monitoring program were prepared and held which showed the changes in the distribution of the computer science students by the levels of the said awareness.

The prospects of further research are outlined in terms of doing the empirical research for the verification of the impact of polygonal numbers explorational activity on the students' motivation to learn mathematics and algorithmization.

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Integrating game development into the secondary school informatics curriculum: A case study from Ukraine

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Abstract. The rapid growth of the video game industry has generated demand for skilled game developers and increased interest in game development education. While many universities now offer game development courses, there is a lack of research on teaching these skills at the secondary school level. This paper presents a case study of designing and implementing a game development course for secondary school students (grades 10-12) in Ukraine. The course was offered as an elective within the informatics curriculum, with the goal of introducing students to basic game development concepts and tools. Course content focused on developing 2D games using the Unity engine, covering topics such as game objects, scripting, physics, user interface, and animation. Evaluation based on student projects, surveys, and teacher observations indicated high levels of engagement and skill development. Challenges included managing the project scope and providing adequate technical support. Recommendations for course improvement and wider adoption are discussed. The study demonstrates the feasibility and value of teaching game development at the secondary level to prepare students for further education and careers in this growing field.

1. Introduction

The video game industry has experienced tremendous growth in recent decades, becoming a significant driver of technological innovation and economic activity [1]. Global game revenues exceeded \$150 billion in 2020, with mobile gaming accounting for nearly half of this total [2]. The increasing size and sophistication of games have generated high demand for skilled developers, with many specialized job roles emerging [3].

To meet this demand, a growing number of universities offer game development courses and degree programs [4, 5]. These programs often emphasize hands-on development using industry-standard tools such as Unity and Unreal Engine [4, 6–8]. Curricular approaches vary, but common elements include interdisciplinary collaboration [9], project-based learning [10], and balancing of technical and creative skills [11].

While the growth of post-secondary game development education has received considerable research attention, fewer studies have examined teaching these concepts at the secondary school level. Incorporating game development into secondary computing curricula presents both opportunities and challenges. It offers a highly motivating context for teaching programming and related skills [12], with clear alignment to professional applications. Game projects also encourage creativity, collaboration, and self-directed learning [13]. However, the technical complexity and



scope of game development pose barriers for younger students and may strain school computing resources [14].

This paper contributes to the limited research on secondary-level game development education through a case study of an elective course offered to informatics students (grades 10-12) at a Ukrainian school. The goals, content, and outcomes of the course are described, highlighting successes and challenges. The study provides a proof of concept for the feasibility and value of teaching basic game development skills to secondary students and offers recommendations for course design and implementation.

2. Background

2.1. Informatics education in Ukraine

Informatics is a mandatory subject in Ukrainian secondary schools, spanning grades 5-11 [15]. The curriculum aims to provide students with a foundation in computer literacy and problem-solving. Topics covered include:

- Algorithms and programming
- Data representation and processing
- Computer networks and the internet
- Cybersecurity and ethics
- Application software (office tools, graphics, multimedia)

Schools have the flexibility to offer additional elective courses to extend and deepen student learning. Common electives include web development, robotics, and 3D modelling [16, 17]. However, game development has not traditionally been part of the standard informatics curriculum.

Several challenges have been noted with informatics education in Ukraine [18]. These include:

- Outdated computing infrastructure in many schools
- Lack of teacher training on current technologies
- Dominance of theoretical over practical instruction
- Limited alignment between curriculum and industry needs

Efforts are underway to modernize the informatics curriculum and teaching methods. These include new standards emphasizing competencies over content knowledge, investment in school computer labs, and professional development for teachers on new technologies [19]. Elective courses provide a mechanism to pilot new topics and approaches within the existing curricular framework.

2.2. Game development education

The growth of game development education at the post-secondary level has been well-documented. A 2014 survey identified over 200 game-related university programs in the United States alone [20]. Common curricular models include:

- Game development within computer science programs [3, 4]
- Specialized game development degrees [21, 22]
- Interdisciplinary programs combining computing, art, and design [11]

While specific course offerings vary, most programs emphasize hands-on development using industry-standard tools and processes [4]. Common topics include programming, computer graphics, game engines, game design, and project management [3]. Many programs also incorporate collaborations with art and design students to create interdisciplinary game development teams [9].

Research has identified several benefits of teaching game development at the post-secondary level. These include:

- Increased student motivation and engagement [12, 23]
- Opportunities for project-based and experiential learning [10]
- Development of professional skills and portfolios [3]
- Preparation for careers in a high-growth industry [20]

Challenges noted in the literature include the rapidly changing technology landscape, the need to balance technical and creative skills, and the difficulty of scoping projects appropriately [4].

At the secondary level, game development has been used in various contexts to support the learning of computing concepts. Tools such as Scratch [24], Alice [25], and Kodu [26] allow students to create simple games while learning basic programming constructs. Research suggests that such game-based learning approaches can increase student motivation and promote deeper understanding compared to traditional instruction [27, 28].

However, studies of teaching professional game development tools and practices at the secondary level remain limited. Cagiltay [13] describes a high school computer game development course in Turkey that found positive impacts on students' problem-solving and creative thinking skills. Robertson and Howells [29] report on a pilot program teaching game design to secondary students in Scotland, noting benefits in engagement and storytelling skills.

The current study aims to build on this limited prior work by investigating the implementation of a Unity game development course within a Ukrainian secondary school informatics program. The goal is to provide a proof-of-concept for the feasibility and value of teaching foundational game development skills in this context and to generate recommendations for future practice and research.

3. Methods

3.1. Research questions

The study was guided by the following research questions:

1. How can a game development course be effectively integrated into a secondary school informatics curriculum?
2. What are the learning outcomes and student perceptions of such a course?
3. What challenges and success factors are identified in implementing the course?
4. What recommendations emerge for the design and wider adoption of secondary-level game development courses?

To address these questions, a case study methodology was employed, focusing on the design, implementation, and evaluation of a game development course at a single school site. Case studies are well-suited to investigating complex educational interventions in real-life contexts [30]. Both quantitative and qualitative data were collected to provide a holistic understanding of the course and its outcomes.

3.2. Research context

The study site was a public secondary school in an urban area of central Ukraine. The school has approximately 800 students in grades 5-11 and offers the standard national informatics curriculum. The school was selected based on the willingness of the informatics teacher and administration to pilot a new elective course.

The elective course was offered to students in grades 10-11 who had completed the core informatics curriculum. These students have prior experience with block-based programming in Scratch (grades 5-6) and text-based programming in Python (grades 7-9). Enrollment was optional, with students self-selecting based on their interests. 20 students (12 male, 8 female) enrolled in the course.

The course was designed and taught by the first author, an informatics teacher with over 6 years of experience and a background in software engineering. The teacher had prior experience with game development as a hobby but had not previously taught it in a formal educational setting.

3.3. Course design

The course was designed as a one-semester elective, meeting for two 45-minute lessons per week (table 1). The goal was to introduce students to foundational game development concepts and tools through hands-on experience creating simple 2D games. The Unity game engine was chosen as the primary development platform due to its widespread industry adoption, extensive learning resources, and free educational licensing.

Table 1. Game development course overview.

Week	Topic	Activities
1-2	Introduction to game development	Game analysis, Unity installation and interface
3-4	Game objects and components	Sprites, transforms, colliders, scripting
5-6	Player control and camera	Input processing, camera follow
7-8	Basic gameplay mechanics	Collectibles, hazards, points
9-10	User interface	Menus, HUD, persistent data
11-12	Polish and packaging	Sounds, visual effects, builds
13-14	Project work	Designing and developing individual games
15-16	Project presentations and reflection	Demos, peer feedback, post-survey

The first half of the course followed a structured sequence introducing key Unity concepts and techniques through interactive demonstrations and mini-projects. Each lesson typically included a brief lecture or demonstration followed by hands-on student work with teacher support. Weekly assignments had students implement specific features in their own projects.

The second half of the course was more open-ended, with students designing and developing their own small-scale games based on a theme or genre of their choice. Students were encouraged to scope their projects to be achievable within the available time and to focus on creating a small set of polished features rather than large, incomplete systems. Regular in-class demos and peer feedback sessions were used to monitor progress and share ideas.

The course concluded with students presenting their completed games and reflecting on their learning experiences. Games were evaluated on technical functionality, creativity, and user experience, with the goal of providing constructive feedback rather than ranking or grading.

Throughout the course, students were provided with links to Unity tutorials, code samples, and other online learning resources to support independent exploration. The teacher also created

a class website to share lesson materials, showcase student work, and facilitate discussion outside of class time.

3.4. Data collection and analysis

Data was collected from multiple sources to provide a comprehensive understanding of the course implementation and outcomes:

- Pre- and post-course student surveys
- Student project artifacts (Unity project files and builds)
- Teacher lesson plans and reflections
- Classroom observations

The pre- and post-course surveys included Likert-scale items measuring students' self-assessed knowledge of game development concepts, comfort with Unity, attitudes towards game development, and future learning intentions. Open-ended items solicited feedback on the course content, structure, and teaching approach. Surveys were administered online and were optional and anonymous.

Student project artifacts were collected and analyzed to assess the application of course concepts and the diversity of game ideas. Teacher lesson plans and reflections were used to understand adaptations made during the course and factors influencing instructional decisions.

The first author's classroom observations provided insight into student engagement, collaboration, and challenges. The author observed three lessons at different stages of the course and recorded field notes.

Quantitative survey data was analyzed using descriptive statistics and paired t-tests to measure pre-post changes. Open-ended survey responses and teacher reflections were analyzed thematically to identify common patterns and illustrative examples. Triangulation across data sources was used to enhance the trustworthiness of findings.

4. Results

4.1. Student learning outcomes

Student survey responses indicate significant gains in self-assessed knowledge of game development concepts and tools. On a 5-point scale from "no knowledge" to "high knowledge", the mean rating increased from 1.8 on the pre-survey to 3.9 on the post-survey ($p < .001$). The largest gains were in understanding game engines, scripting, and 2D game mechanics.

By the end of the course, all students successfully completed a playable 2D game. Games spanned a range of genres, including platformers, puzzles, endless runners, and shoot 'em ups. Common features implemented included player control, collision detection, scoring systems, level progression, and sound effects. Several students incorporated more advanced techniques such as particle systems, scriptable objects, and persistent data storage.

While the scope and polish of the final projects varied, all demonstrated a functional understanding of core Unity concepts and the ability to combine them into a cohesive game experience. Post-course reflections indicated that students were generally satisfied with their games and felt a sense of pride in their accomplishments. As one student noted, "I never thought I could create something like this on my own".

4.2. Student engagement and attitudes

Classroom observations and teacher reflections indicated high levels of student engagement throughout the course. Students actively participated in discussions, asked questions, and experimented with different game ideas. Several students went beyond the assigned projects to independently explore more advanced Unity features or try out ideas from online tutorials.

Survey results show a significant increase in student interest in game development and intent to pursue further learning. The percentage of students indicating that they were “interested” or “very interested” in game development rose from 45% on the pre-survey to 90% on the post-survey. Similarly, the percentage planning to continue learning game development after the course rose from 40% to 85%.

Open-ended survey responses highlight the motivating and engaging nature of the game development context. Representative quotes include:

“I never liked informatics class before, but making games is actually fun. It doesn’t feel like schoolwork.”

“I used to think programming was boring, but now I see how it can be used to create cool things. I want to make more games and maybe even study this in university.”

“The best part of the class was seeing my own ideas come to life on the screen. It’s amazing to think that I created something that other people can actually play.”

These responses suggest that the game development course not only increased student knowledge and skills but also positively impacted their attitudes towards computing and their motivation to learn.

4.3. Implementation challenges and success factors

While the overall implementation of the course was successful, several challenges were encountered. One was the wide range of prior programming experience among students. While all had some exposure to Python, some struggled with the transition to C# and object-oriented programming concepts used in Unity. The teacher had to provide additional scaffolding and support for these students, while also keeping more advanced students engaged.

Another challenge was the complexity of the Unity interface and the wide range of features available. Even with a focus on 2D games, students could easily become overwhelmed by the options and menus. The teacher had to carefully balance giving students the freedom to explore by providing clear guidance and limiting the scope of projects.

Technical issues were also encountered, particularly with the school’s ageing computer lab. Some machines struggled to run Unity smoothly, leading to frustration and lost work time. The teacher had to troubleshoot hardware and software problems and find workarounds, such as using lower-resolution graphics or older versions of Unity.

Despite these challenges, several factors were identified as contributing to the success of the course. One was the engaging and motivating nature of game development itself. Students were excited to create their own interactive experiences and see their ideas come to life on the screen. This intrinsic motivation helped them persevere through difficult concepts and technical obstacles.

Another success factor was the use of a structured but flexible curriculum that allowed for student choice and creativity. The first half of the course provided a solid foundation in Unity concepts through guided projects, while the second half gave students the freedom to design their own games. This balance of structure and autonomy seemed to support both learning and engagement.

The teacher’s own background in game development and ability to provide individualized support was also critical. The teacher was able to draw on personal experience to explain concepts, suggest solutions to problems, and inspire students with examples of professional games. The small class size allowed for plenty of one-on-one interaction and tailored feedback.

Finally, the use of online resources and communities extended learning beyond the classroom. Students were able to find tutorials, assets, and inspiration from the vast Unity ecosystem and connect with other developers online. This exposure to real-world practices and professionals helped make the learning experience authentic and relevant.

5. Discussion

The results of this case study suggest that integrating game development into secondary school informatics education is feasible and can positively impact student learning, engagement, and attitudes. Students successfully learned Unity concepts and tools and applied them to create their own games. The game development context proved highly motivating, with students expressing increased interest and intent to further pursue computing and game development.

These findings align with prior research on the benefits of game design activities for student learning and engagement [27, 28]. Creating games offers a powerful context for learning programming concepts through immediate feedback, experimentation, and creative expression. It also aligns with students' interests and experiences in an increasingly gamified world.

At the same time, the study highlights challenges in implementing game development education at the secondary level. The technical complexity of professional tools like Unity can be a barrier for both students and teachers. Careful instructional design is needed to manage cognitive load and scope projects appropriately. Schools may also lack the necessary hardware and infrastructure to support intensive game development work.

To address these challenges, several recommendations emerge from the study:

- Start with simple, constrained projects and gradually increase the complexity
- Provide ample structure and scaffolding, especially for programming concepts
- Leverage online resources and communities to support learning
- Allow for student choice and creativity within projects
- Ensure adequate technical infrastructure and support
- Provide teacher' professional development on game development tools and pedagogy

More broadly, the study suggests the need for greater alignment between secondary computing education and the realities of the professional software industry. With the growing economic and cultural importance of games and interactive media, exposure to these domains can help prepare students for future careers and engage them in computing when it is most relevant to their lives and interests.

Despite the findings' generalizability being limited by the small sample size and single school context, the study offers a proof of concept for integrating game development into secondary informatics curricula.

6. Conclusion

This case study investigated the design, implementation, and outcomes of a game development course within a Ukrainian secondary school informatics program. Through a combination of guided and open-ended Unity projects, students successfully learned and applied game development concepts and tools. The course proved highly engaging, with students expressing increased interest and intent to pursue further game development learning.

While challenges were encountered in terms of technical complexity and resources, the study demonstrates the feasibility and value of introducing professional game development practices and tools at the secondary level. With appropriate instructional design and support, such courses can align computing education with student interests and real-world applications, and prepare them for further study and careers in a high-growth industry.

The findings suggest several avenues for future research and practice, including developing and validating instructional models and resources for secondary game development education, examining impacts on student learning and engagement across diverse contexts, and exploring partnerships with industry and higher education to provide authentic learning experiences.

As the demand for creative and technical talent in the game industry continues to grow, integrating game development into secondary computing curricula represents a promising opportunity to engage and inspire the next generation of developers and innovators.

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Development of an elective course on Scratch programming for specialized computer science education in lyceums

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Abstract. This paper presents the development and evaluation of an elective course on Scratch programming specifically designed for specialized computer science education in lyceums. The course aimed to develop students' algorithmic thinking and digital competencies in 10th and 11th grade through interactive project-based learning. A 12-week pedagogical experiment using a pre-test/post-test design was conducted to assess the course's effectiveness. The results demonstrated significant improvements in students' Scratch programming skills and computational thinking abilities, as confirmed by statistical analysis of test scores. The students also reported high satisfaction with the course. This study highlights the potential of integrating a targeted Scratch programming curriculum into lyceum education to foster crucial computational thinking skills and creativity, providing a strong foundation for further computer science learning.

1. Introduction

In the evolving landscape of K-12 education, the introduction of programming skills through block-based environments such as Scratch has become increasingly common [1]. Scratch, developed by the MIT Media Lab, is a visual programming language that allows users to create interactive stories, games, and animations by dragging and dropping code blocks [2]. The importance of studying block-based programming lies in its potential to provide an accessible and engaging entry point into the world of programming, especially for younger students who may find traditional text-based programming intimidating [3].

The integration of Scratch programming into K-12 education has been widely studied, with researchers investigating its impact on students' computational thinking skills, academic performance, and attitudes towards programming [4, 5]. A growing body of literature has also explored the use of Scratch programming in various academic disciplines, such as mathematics [6], science [7], and STEAM [8].

Despite the increasing interest in Scratch programming, there is a need for more comprehensive research on its implementation and effectiveness in specialized computer science education at the lyceum level. This study aims to address this gap by developing and evaluating an elective course on Scratch programming for lyceum students, focusing on fostering algorithmic thinking and digital competencies through project-based learning.



2. Literature review

A systematic review by Batni et al. [9] analyzed 27 articles published between 2018 and 2022 to identify current research trends in using Scratch for K-12 education. The review found that Scratch is commonly used to teach programming concepts in computer science and ICT subjects, as well as in other academic disciplines such as mathematics, science, and languages. Mixed methods research designs were the most prevalent, and the studies generally reported positive impacts of integrating Scratch programming into K-12 curricula. However, the review also highlighted the need for more comprehensive, longitudinal studies with diverse samples to understand better the long-term effects of learning Scratch on students' computational thinking skills and academic performance.

Several studies have investigated the use of Scratch programming in specific academic disciplines. In mathematics education, Rodríguez-Martín et al. [10] found that Scratch can be used to develop both students' mathematical ideas and computational thinking. The authors conducted an experiment with sixth-grade students and observed improvements in their understanding of mathematical concepts and computational thinking skills after engaging in Scratch programming activities.

In science education, Ntourou et al. [11] examined the impact of using Arduino and visual programming on fifth-grade students' self-efficacy, motivation, computational thinking, and perceptions of electricity. While the effects on motivation and self-efficacy could not be demonstrated, the study showed clear improvements in students' conceptual understanding of electricity and computational thinking skills.

Scratch programming has also been applied in STEAM education. Pereira and Lopes [12] reported on a four-month STEAM project in which students aged 12-15 created electronic games using Scratch. The authors found that students engaged in playful, creative, and collaborative activities to transform realities, demonstrating the potential of Scratch as an efficient platform for STEAM-related learning.

The impact of Scratch programming on students' attitudes and self-efficacy towards programming has also been investigated. Yukselturk and Altioek [5] conducted a study with preservice information technology teachers to examine the effects of programming with Scratch on their self-efficacy perceptions and attitudes towards computer programming. The results showed significant improvements in the participants' self-efficacy and attitudes after engaging in Scratch programming activities.

While these studies provide valuable insights into the application of Scratch programming in various educational contexts, more research is needed on its implementation and effectiveness in specialized computer science education at the lyceum level. The current study aims to contribute to this body of knowledge by developing and evaluating an elective course on Scratch programming for lyceum students.

3. Methodology

3.1. Course development

The elective course on Scratch programming was designed to cater to the needs of lyceum students interested in pursuing specialized computer science education. The course content was developed based on a thorough review of existing literature on Scratch programming and computational thinking, as well as consultations with experienced computer science educators.

The course consisted of six modules, each focusing on a specific aspect of Scratch programming and computational thinking:

1. Introduction to Scratch and programming concepts
2. Algorithms and problem-solving
3. Variables and data types

4. Conditional statements and loops
5. Functions and modularization
6. Project development and presentation

Each module included a combination of theoretical explanations, practical exercises, and project-based assignments. The course materials were designed to be interactive and engaging, focusing on fostering students' creativity and problem-solving skills.

3.2. Participants

The study involved two groups of lyceum students: a group of 10th-grade students ($n=10$) and a group of 11th-grade students ($n=10$). The participants were selected based on their interest in computer science and their willingness to attend the elective course on Scratch programming.

3.3. Pedagogical experiment

The pedagogical experiment lasted 12 weeks. Weekly sessions lasted 90 minutes each, and they were held in a computer lab equipped with individual workstations for each student.

The experiment followed a pre-test/post-test design to assess the effectiveness of the elective course on students' Scratch programming skills and computational thinking abilities. At the beginning of the course, participants completed a pre-test consisting of a series of Scratch programming tasks and a computational thinking assessment. The same tests were administered at the end of the course as a post-test.

Throughout the course, students worked on various programming exercises and projects, both individually and in small groups. The instructor provided guidance and support, encouraging students to explore different programming concepts and techniques.

3.4. Data collection and analysis

Data were collected through a combination of pre-test and post-test scores, student projects, and a course satisfaction survey. The pre-test and post-test scores were analyzed using paired t-tests to determine if there were significant differences in students' Scratch programming skills and computational thinking abilities before and after the course.

Student projects were evaluated based on a rubric that assessed the complexity of the program, the use of programming concepts, and the overall functionality and creativity of the project. The course satisfaction survey consisted of Likert-scale and open-ended questions, providing insights into students' perceptions of the course and their learning experiences.

4. Results

4.1. Initial stage

At the initial stage of the experiment, we determined the baseline level of Scratch programming skills and students' interest in the experiment. Survey results showed that the majority of students (90%) had studied Scratch at school, but only half of them had used Scratch to create games or projects. About 30% of students had participated in Scratch programming competitions, and all participants expressed a desire to study Scratch in Years 11-12. Students rated their initial Scratch proficiency at an average of 6.3 points out of 10 (figure 1).

4.2. Formative Stage

During the formative stage, 11 lessons were conducted, during which students completed 6 optional course tasks and created their own game using the acquired knowledge and skills. Participants demonstrated high engagement and a creative approach during the learning process, as evidenced by their feedback:

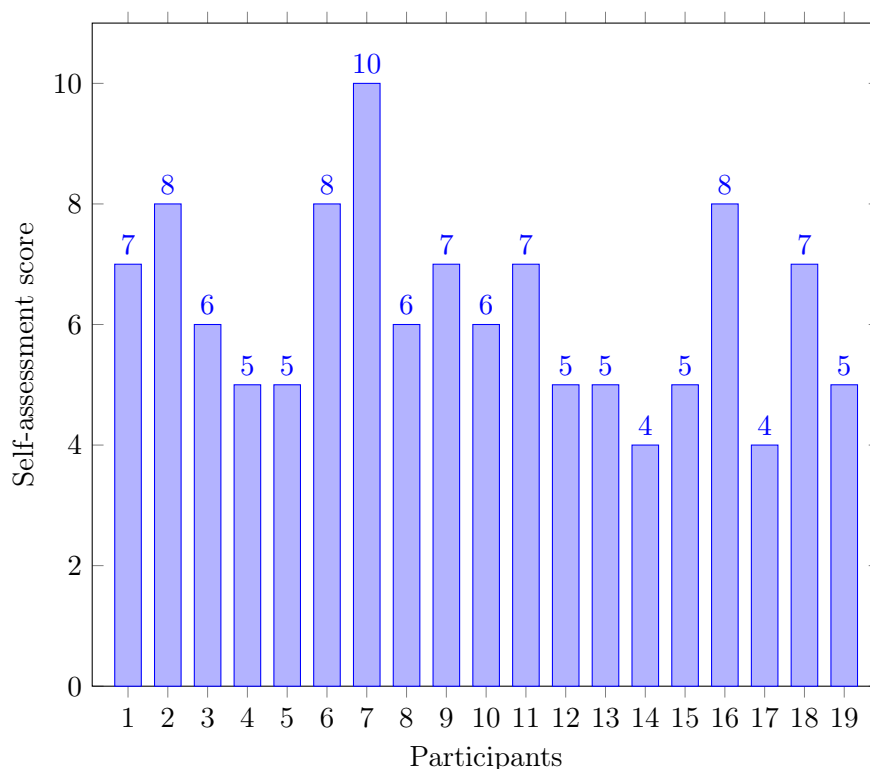


Figure 1. Assessment results of participants' self-evaluated Scratch programming skills.

"Interesting tasks, clearly described. Could use separate lessons on algorithms and events." (D. A.)

"Ms Karina, your work is extensive; one can clearly see how much effort was put in. I would recommend adding more developments to cult games, such as Mario and Galaga, and some fighting games. Thank you." (K. U.)

4.3. Assessment stage

At the assessment stage, students rated the optional course tasks at an average of 8.5 points out of 10. Most participants (65%) would recommend this optional course to their friends or classmates as a programming learning resource, and 60% plan to continue using the course to work through other sections. Half of the students expressed interest in participating in Scratch programming competitions using the knowledge gained during the course.

Students rated their Scratch proficiency after completing the optional course at an average of 8.6 points out of 10, indicating a significant improvement in their programming skills (figure 2).

Participants also provided positive feedback about the optional course:

"The course is good, the instruction is brilliant, would like to do more visual work in games." (L. D.)

"Cool exercises, clearly described; there are links to completed projects so you can see straight away what the end result will be. Wishing you further development, this course is suitable for both older and younger pupils." (K. M.)

"Outstanding! I expected nothing less!" (A. K.)

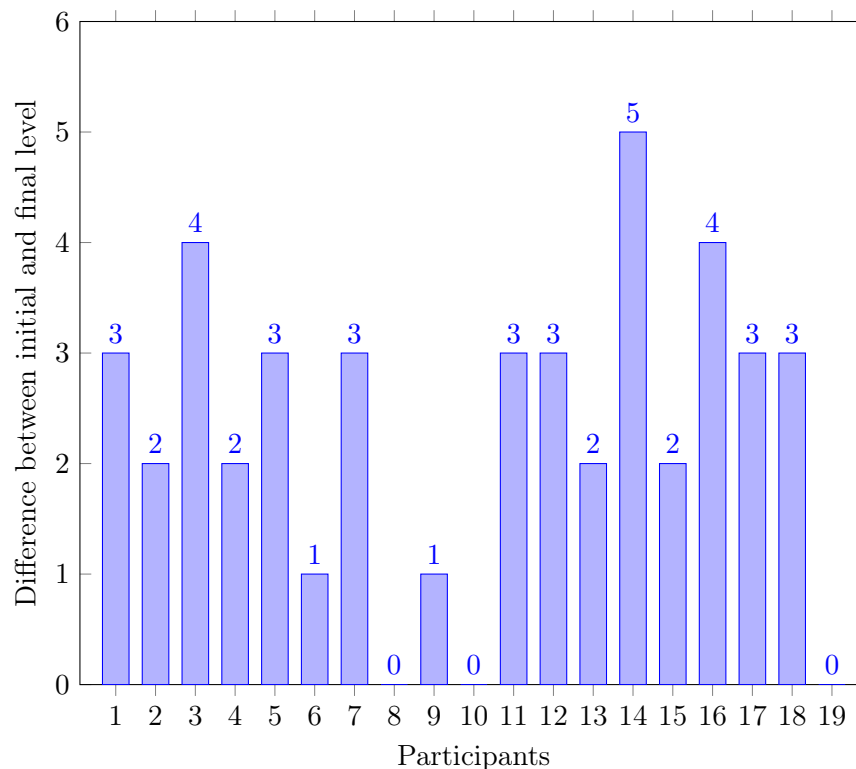


Figure 2. Results showing the increase in participants' Scratch proficiency level.

The evaluation of students' project implementations according to the developed criteria showed that most participants successfully applied their acquired knowledge and skills in their projects. The average project score was 5.1 points out of 6 possible points (table 1).

Table 1. Evaluation of students' project implementations.

Project evaluation criterion	Average score
Task compliance	1.0
Completion	0.8
Proficiency	0.9
Creative approach	1.0
Code optimisation	1.0
Code culture	0.5
Total score	5.1

4.3.1. Scratch programming skills. The paired t-tests revealed significant improvements in students' Scratch programming skills from pre-test to post-test in both the 10th-grade group ($t(9) = -8.12$, $p < 0.001$) and the 11th-grade group ($t(9) = -9.45$, $p < 0.001$). The mean scores increased from 4.2 (SD = 1.3) to 8.1 (SD = 1.1) in the 10th-grade group and from 5.1 (SD = 1.5) to 9.2 (SD = 0.8) in the 11th-grade group.

These results indicate that the elective course on Scratch programming was effective in improving students' programming skills, regardless of their grade level.

4.3.2. Computational thinking abilities. The computational thinking assessment also showed significant improvements in both the 10th-grade group ($t(9) = -6.89$, $p < 0.001$) and the 11th-grade group ($t(9) = -7.56$, $p < 0.001$). The mean scores increased from 6.3 (SD = 1.2) to 9.1 (SD = 0.9) in the 10th-grade group and from 6.8 (SD = 1.4) to 9.5 (SD = 0.7) in the 11th-grade group. These findings suggest that engaging in Scratch programming activities can help students develop and enhance their computational thinking skills.

4.3.3. Student projects. The evaluation of student projects revealed a high level of engagement and creativity among the participants. Students created a variety of interactive stories, games, and simulations using Scratch, demonstrating their ability to apply the programming concepts and techniques learned throughout the course. The complexity and functionality of the projects varied, with some students creating more advanced programs that incorporated multiple programming concepts and user interactions. Overall, the projects demonstrated students' growth in Scratch programming skills and their ability to apply computational thinking in a creative context.

4.3.4. Course satisfaction. The course satisfaction survey results indicated that the majority of students had a positive experience with the Scratch programming elective course. On a 5-point Likert scale, the average rating for overall satisfaction was 4.5 (SD = 0.6) in the 10th-grade group and 4.7 (SD = 0.5) in the 11th-grade group. Students appreciated the interactive nature of the course, the hands-on programming exercises, and the opportunity to work on projects that aligned with their interests. Many students expressed a desire to continue learning Scratch programming and explore more advanced topics in computer science.

5. Discussion

The results of this study demonstrate the effectiveness of the optional Scratch programming course for developing programming skills and computational thinking in secondary school students. Participants showed significant improvement in their skills, high engagement and course satisfaction, and successfully applied their acquired knowledge in their projects. The significant improvements in students' Scratch programming skills and computational thinking abilities align with previous research that has highlighted the positive impact of Scratch programming on students' learning outcomes [5].

The systematic review by Batni et al. [9] emphasized the need for more comprehensive, longitudinal studies with diverse samples to understand better the long-term effects of learning Scratch on students' computational thinking skills and academic performance. While the current study provides valuable insights into the effectiveness of an elective Scratch programming course for lyceum students, future research should consider larger sample sizes and longer-term follow-up assessments to evaluate the sustainability of the observed learning outcomes.

The positive course satisfaction ratings and the high level of engagement observed in student projects suggest that Scratch programming can be an effective tool for motivating and inspiring students to pursue further studies in computer science. By providing an accessible and engaging entry point into programming, Scratch can help bridge the gap between introductory programming concepts and more advanced topics in computer science education.

6. Conclusions

In conclusion, the development and evaluation of an elective course on Scratch programming for specialized computer science education in lyceums have shown promising results in terms of students' programming skills, computational thinking abilities, and overall satisfaction. The study highlights the potential of integrating Scratch programming into lyceum curricula to foster algorithmic thinking, creativity, and digital competencies among students.

As the demand for computer science education continues to grow, it is essential to develop and implement effective teaching strategies that engage and inspire students. This study's findings suggest that Scratch programming can be a powerful tool for introducing students to the world of programming and computational thinking, paving the way for future success in specialized computer science education and beyond.

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A curriculum recommendation system using a vector database for challenge-based learning

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Abstract. This paper proposes a methodology and describes the implementation of a graph-based curriculum recommender system for flexible, personalized, challenge-based learning. The central element of the proposed recommendation process is an algorithm that uses mixed integer programming to optimize curriculums based on multiple constraints, including logical sequencing and credit accumulation requirements. A procedure for assessing grades based on preliminary clustering of students using the k -nearest neighbors method is proposed. The key to implementing the proposed approach is generating performance vectors and estimating grades for tasks that have not yet been completed by students, which is necessary for personalizing learning recommendations. The architecture of a recommender system based on a vector database, the features of the algorithm for generating recommendations, and the results of assessing the degree of accuracy of estimates are described; generated synthetic data were used to conduct computational experiments.

1. Introduction

Within the continuously evolving domain of higher education, there is an imperative demand for pedagogical innovations that facilitate academic excellence and equip students to navigate the complexities of today's global and professional landscapes. Challenge-based learning (CBL) is an educational approach that engages students in real-world problem-solving, promoting learning and developing critical thinking, creativity, and collaboration skills. Unlike traditional learning models, CBL is student-centered pedagogical conception and focused on real-world problems, requiring students to go through research, solution development, and implementation stages, often working in teams. Through this process, students not only acquire subject matter knowledge, but also develop essential soft skills such as communication, teamwork, and problem-solving. CBL's hands-on approach also increases student motivation and retention, as students see the direct impact of their efforts on solving real-world problems. By preparing students to tackle the challenges of future with confidence and competence, challenge-based learning represents a forward-thinking shift in education that meets the needs of a rapidly changing world [1].

CBL is conceptualized as an innovative pedagogical strategy based on immersing students in real-world, practical problems that require collaborative, creative teamwork and critical thinking



to find solutions. Innovation in CBL encompasses both a mercantile aspect, focusing on creating new products, and a social innovation aspect aimed at generating social and cultural values. CBL is becoming one of the key methods for developing competencies and self-learning abilities in students of knowledge-intensive university specialties. Student-oriented learning is growing in the following areas: the formation of new pedagogical approaches, technological integration, and interaction with industry and development support [2–4].

The effectiveness of the implementation and improvement of CBL systems is largely due to the use of modern educational information technologies, among which, in this context, a special place is occupied by recommender systems for supporting academic choice in the learning process. As society increasingly demands specialized skills, education must adapt to each individual's unique interests and abilities. Therefore, user-centered curricula are becoming paramount in today's educational environment to provide a personalized learning experience that promotes growth and mastery. Curriculum recommendation systems are emerging as a valuable tool in the educational landscape, offering personalized guidance to students in their learning journey. These systems, leveraging data-driven techniques, are designed to analyze individual learning progress and preferences, enabling the creation of tailored curriculum and helping students optimize their course selection to achieve their learning goals, providing support for the choice of an individual educational trajectory based on the combination of the interests of the student with the general requirements for the construction of the curriculum, taking into account current and predicted assessments of educational achievement [5].

The introduction of artificial intelligence (AI) into educational recommendation systems represents a transformative approach to personalizing the learning experience. AI algorithms can analyze vast amounts of data on student behavior, preferences, and performance to create highly personalized content recommendations. Using vector databases that excel at processing complex, multidimensional data, these systems can efficiently process and store embeddings generated by AI models containing data on students' current competencies, find learning paths, and provide suggestions to shape each student's unique learning path. This approach not only increases the relevance of recommended resources but also adapts to changing student needs, thereby contributing to a more effective educational experience.

This paper proposes a methodology and describes the implementation of a graph-based curriculum recommender system for personalized CBL. The central element of the proposed recommendation process is an algorithm that uses mixed integer programming (MIP) to optimize curriculums based on multiple constraints, including logical sequencing and credit accumulation requirements. A procedure for assessing grades based on preliminary clustering of students using the k -nearest neighbors (kNN) method is proposed. The key to implementing the proposed approach is generating performance vectors and estimating grades for tasks that have not yet been completed by students, which is necessary for personalizing learning recommendations. The architecture of a recommender system based on a vector database, the features of the algorithm for generating recommendations, and the results of assessing the degree of accuracy of estimates are described; generated synthetic data were used to conduct computational experiments.

2. State of the art

There is extensive literature devoted to the issues of development, implementation and evaluation of the effectiveness of recommender systems in education; a detailed review is given in [5]. Li and Ye [6] presents a personalized online education platform based on a collaborative filtering algorithm, developed using cross-platform compatible HTML5 and high-performance hybrid programming framework approach. A methodology for automated development of individualized curricula is presented in [7], the proposed system combines ideas from graph theory, performance modeling, machine learning, explainable recommendations, and an intuitive user interface. The application of supervised machine learning methods such as decision tree,

random forests and support vector machine to predict learning success is discussed in [8]. Furthermore, the study focused on the importance of input features, which had a great impact on simplifying the overall classification process by reducing the number of input features, which consequently led to a better result. To develop methods for improving the efficiency of learning, a hierarchical model of progressive improvement (CHPI) is developed in [9], which is based on the methods of cluster analysis and context-sensitive data envelopment analysis (DEA). CHPI clusters the ontological features of students, uses the context-sensitive DEA method to stratify students of different classes, and calculates measures such as obstacles to determine the control path for individuals with ineffective learning processes. Learning strategies are determined according to the gap between the ineffective individual to be improved and the individuals on the control path. Hlazunova and Ponzel [10] analyzes the main problems in the implementation of a recommendation system for building an individual study plan for a higher education student identifies the main ways to implement such a system, and builds a basic algorithm for recommendation system that can provide top disciplines for a student to study based on his or her previous learning outcomes, the learning outcomes of students of the same specialty for a certain period, and the factor of similarity of subjects and the choice of his or her specialization. Delahoz-Domínguez and Hijón-Neira [11] presents the results of developing a system for providing personalized and contextually relevant recommendations for choosing a university degree. The system aims to optimize the match between student profiles and potential academic programs using advanced machine learning models, including XGBoost, Random Forest, GLMNET, and kNN. Roepke et al. [12] presents the AISTudyBuddy project, with a focus on using rule-based AI and process analytics to support learning planning and cohort monitoring. The concept of a reference architecture and data model for learning path analytics is presented, as well as details on developing custom applications, to ensure quality in learning planning and monitoring of student cohorts.

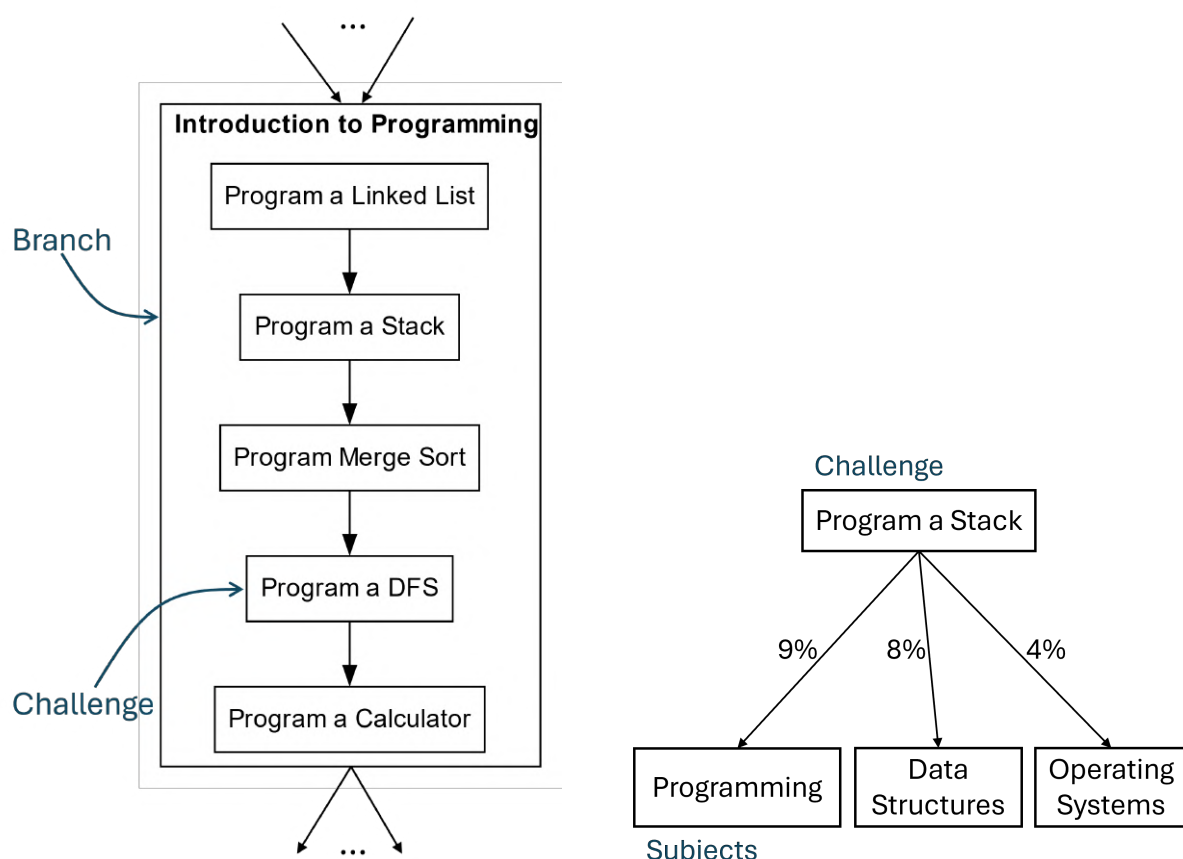
Of particular interest are works devoted to the use of machine learning methods in the problems of building educational recommendation systems. Abyaa et al. [13] investigates the feasibility of predicting a learner's personality based on educational data through supervised learning algorithms. The study underscores the potential of educational data in enhancing adaptive learning systems by tailoring learning paths and resources according to learners' personality traits, thereby mitigating negative learning outcomes associated with certain personality aspects. The "RSU-ML-PL" algorithm [14] was developed to improve individual learning outcomes in an e-learning environment by identifying at-risk learners and providing personalized self-guided learning programs. Five algorithms, logistic regression, k -nearest neighbors, decision trees, random forest classifier, and support vector machine, are implemented to build a classification model that identifies learners who need additional support. Riad et al. [15] proposes a new adaptive e-learning system that enhances recommendation precision and quality by incorporating learners' motivation levels alongside content-based filtering techniques. An important component of educational recommendation systems is information technologies for assessing and predicting student grades. Badal and Sungkur [16] provide a predictive model to forecast students' performance (grade/engagement) and to analyze the effect of online learning platform's features. The model created in this study made use of machine learning techniques to predict the final grade and engagement level of a learner. Nachouki et al. [17] proposed a model based on random forest methodology to predict students' course performance using seven input predictors and find their relative importance in determining the course grade.

3. Graph course model

The construction of recommendation systems that support students' choice of individual educational trajectories first requires the building of mathematical models of educational programs and courses that describe the composition and sequence of educational tasks and

work. A course is described by two main components: branches and tasks. In this context, a “branch” is analogous to one thematically dedicated part of a course and includes several “tasks” representing an assignment that must be completed either by an individual student or by a group. The tasks within a branch are arranged in a certain sequence, with the completion of the branch depending on the successful completion of the last task in the prescribed order. An example of a branch with some related tasks is shown in figure 1(a). Individual branches in a course system can be conceptualized as “aggregated” nodes that together form a larger “branch graph”. The key principle in this framework is the precondition requirement: a branch can only be chosen if all its previous branches have been completed. The graph defined by these branches is a directed acyclic graph, describing a one-way progression without cycles, providing a linear path of academic progress for students.

In the context of designing a course system, it is important to establish a mapping between individual tasks and broader academic subjects. To ensure compliance with these rules, a system is needed to track students’ progress across the broad subjects. In practice, this involves assigning each task to one or more subjects, together with an assessment of the extent to which completing the task contributes to the requirements of the subject. For example, as illustrated in figure 1(b), the topic “Program the Stack” task can be associated with multiple educational items, each with a different percentage contribution.



(a) Branch and associated challenges.

(b) Subject mapping to challenges.

Figure 1. Examples for challenge-based approach.

Within the graph-based course model, a recommendation is conceptualized as a selection

of challenges. The recommendation framework operates under a set of specific constraints to ensure that the recommendations are both practical and effective:

1. **Graph constraints:** Recommendations must adhere to the pre-established graph structure, respecting both the hierarchical order of branches and the sequential arrangement of challenges within each branch.
2. **Target subjects:** The recommendation must encompass a predetermined set of educational subjects that are required for completion, in line with educational objectives.
3. **Total credit count:** There is a minimum credit count that the recommendation should fulfill, ensuring that the student meets academic credit requirements.
4. **Weights for challenges:** Every challenge is assigned a weight, indicative of its anticipated difficulty level for the student.

An objective of the recommendation process is to minimize the total weight of the selected challenges, aiming to balance the academic load effectively.

4. Recommendation system architecture

The recommendation system was designed as a REST API, prioritizing ease of integration with other services. This API serves as the interface for generating personalized recommendations for individual users. We chose Flask (<https://flask.palletsprojects.com/en/3.0.x/>) for implementing the REST API and PostgreSQL (<https://www.postgresql.org>) for the database, based on their robustness and compatibility with our requirements.

Additionally, to enhance user experience and provide a tangible demonstration of the system's capabilities, we developed a simple frontend using React. This not only serves as an interface for the recommendation system but also visually represents the branch graph.

For database interactions, we opted for an Object-Relational Mapping (ORM) approach, using SQL Alchemy (<https://www.sqlalchemy.org>). This decision was driven by the desire for a streamlined and efficient process for handling database operations. A significant aspect of the development was the splitting of the recommendation algorithm into two distinct parts: firstly, the calculation of weights for each challenge, and secondly, the optimization problem solution. One of the most notable was the decision against implementing an explicit caching mechanism. Instead, we leveraged a vector database extension Pgvector (<https://github.com/pgvector/pgvector>) of PostgreSQL to store user embeddings. These embeddings, used to query similar users, significantly reduce database traffic as they do not require re-calculation with every recommendation process. Initially, a caching solution might have been considered for this purpose; however, integrating this data directly into the database presents advantages in terms of querying efficiency and reduces the complexity associated with maintaining a separate cache. Figure 2 offers the recommendation system architecture.

5. Recommendation algorithm

In tackling the task of recommending challenges within the graph model, an algorithmic approach was employed works according to a two-part procedure:

1. **Data preprocessing and grade estimation:** Initially, we estimate grades for all challenges that the user has not yet completed, setting the foundation for personalized challenge recommendations. We focus on the task of assigning an estimated value to each challenge, serving as a metric that predicts a user's performance on that specific challenge.
2. **Recommendation computing via MIP:** The optimal set of tasks is determined using MIP, enabling to identification of the most suitable challenges to recommend to student based on their unique learning path and performance. The objective of MIP is to determine

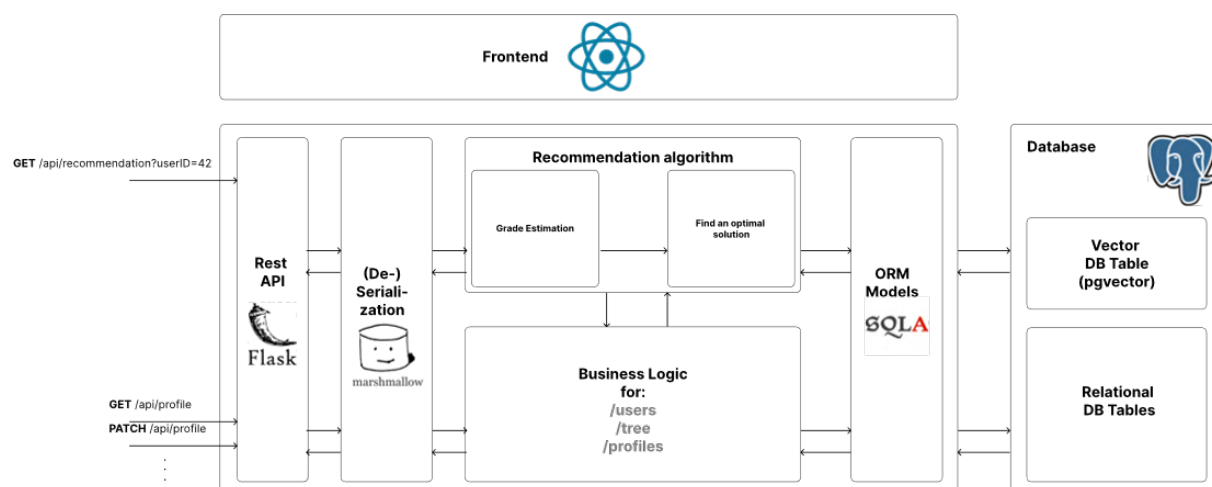


Figure 2. Final architecture of recommendation system.

the optimal subset within the challenge graph while adhering to a defined set of constraints. We defined that optimal selection coincides with an overall optimal average grade on the predicted set of challenges.

The grade evaluation stage of the recommendation algorithm is the part that inputs personalized information from users in the recommendation generation process. The students are pre-clustered using kNN, and the averaged grades of the k -nearest neighbors are then used as the evaluation score for the task. In the final step, we derive a specific estimation for the target by computing the average of the values along the target dimension within the selected k -nearest objects. The historical performance data of students is used as individual records in the vector embedding to generate the grades. For performance improvement, we implemented a technique known as vector imputation. The objective of this method is to populate empty dimensions with meaningful values. We considered four distinct imputation strategies: Mean, Median, kNN, and Iterative Imputation. The mean and median imputation strategy involves filling empty values with the mean or median of the entire dataset within that dimension.

The rating scores for each task are used to assign a difficulty factor to the task. Specifically, a lower rating prediction (indicating a higher level of difficulty) is mapped to a higher difficulty factor in the MIP model, and conversely, a higher rating prediction (indicating ease of execution) is associated with a lower difficulty factor. The goal of the MIP algorithm is to select a set of tasks that, when combined, minimize the total sum of the difficulty factors. The selection process is carried out subject to a set of constraints:

1. **Graph constraints:** For a task selection to be considered valid, it must satisfy the constraints of the graph model structure, namely, the next task can only be selected if all tasks that precede it, either directly or indirectly (i.e., in the previous branch), have also been completed.
2. **Minimum total credits:** The curriculum recommendation must meet the requirement that the total credits associated with the chosen tasks exceed the established threshold.
3. **Target subjects:** Within the algorithm, we have incorporated the concept of configurable target subjects as another key feature. These can be likened to obligatory courses that a student is required to take. This design affords us the versatility to provide user-centric recommendations while introducing a level of rigidity, ensuring essential subjects are included based on specific requirements.

In terms of technical aspects, it's noteworthy that we used a solver-independent language for MIP realization. The library facilitating this functionality is *pyomo* [18], offering the advantage of decoupling the solver implementation in the background, allowing for flexibility in selecting different solvers; currently, our implementation utilizes an open-source CBC solver COIN-OR CBC Optimization Suite (<https://zenodo.org/records/13347261>).

6. Vector database

A vector database is designed to efficiently store and retrieve vectorized data. Due to the distinctive data format supported by a vector database, it enables highly efficient querying of vectors, especially in the context of similarity search. Using a vector database to implement a recommendation system provides the following benefits:

1. The need for a separate kNN implementation is eliminated by leveraging the highly efficient internal similarity search capability of the vector database. This allows searching for similar vectors quantified by metrics such as $L2$ distance or cosine similarity. In essence, this built-in functionality serves as an equivalent of kNN.
2. Storing data in a highly aggregated form encapsulated by a performance vector allows implementation of a compact embedding characterizing a student's academic profile. This approach saves network resources and minimizes the number of database queries.

7. Grade prediction assessment

We have implemented a concept aimed at consolidating a student's performance into a unified vector. The performance vector is designed to encapsulate a numeric value for each subject, with a higher value indicative of superior performance. To ensure a standardized representation, we have normalized the performance values, scaling them between zero and one.

A significant hurdle is the scarcity of real-world data. Consequently, there was a pressing need to generate synthetic data that closely mimics real-world scenarios, for testing and refining the recommendation algorithm. To address this, we crafted an example branch graph, the design of the challenges and branches in this graph drew inspiration from various existing study plans, ensuring semantic coherence and relevance. The constructed graph, representing the course structure, includes 200 challenges across 38 branches and covers 39 subjects. The more intricate aspect of our data generation process involved creating student histories. The overarching objective here was to ensure that a student's grades are reflective of a diverse range of students at different stages of their academic journey. This process was divided into two stages:

1. **Generation of expected performance:** For each student, we generate an expected performance level across all subjects. The generation of expected performance for each student hinges on ensuring correlated performance across subjects while allowing for the customization of means and standard deviations for different subjects.
2. **Generation of student histories:** Building on the expected performance levels, we then generated user histories for each student. This stage involved assigning grades for challenges based on the expected subject performance, thereby creating a realistic and varied set of academic records. Two variables are introduced to enhance the realism of the grading process: Challenge Difficulty and Student Performance Variability.

We crafted a tailored framework (figure 3) to assess the quality of grade estimation. The assessment framework comprises three pivotal stages:

1. Performance vector calculation.
2. Search for similar users and estimation of performance.
3. Evaluation of the estimation.

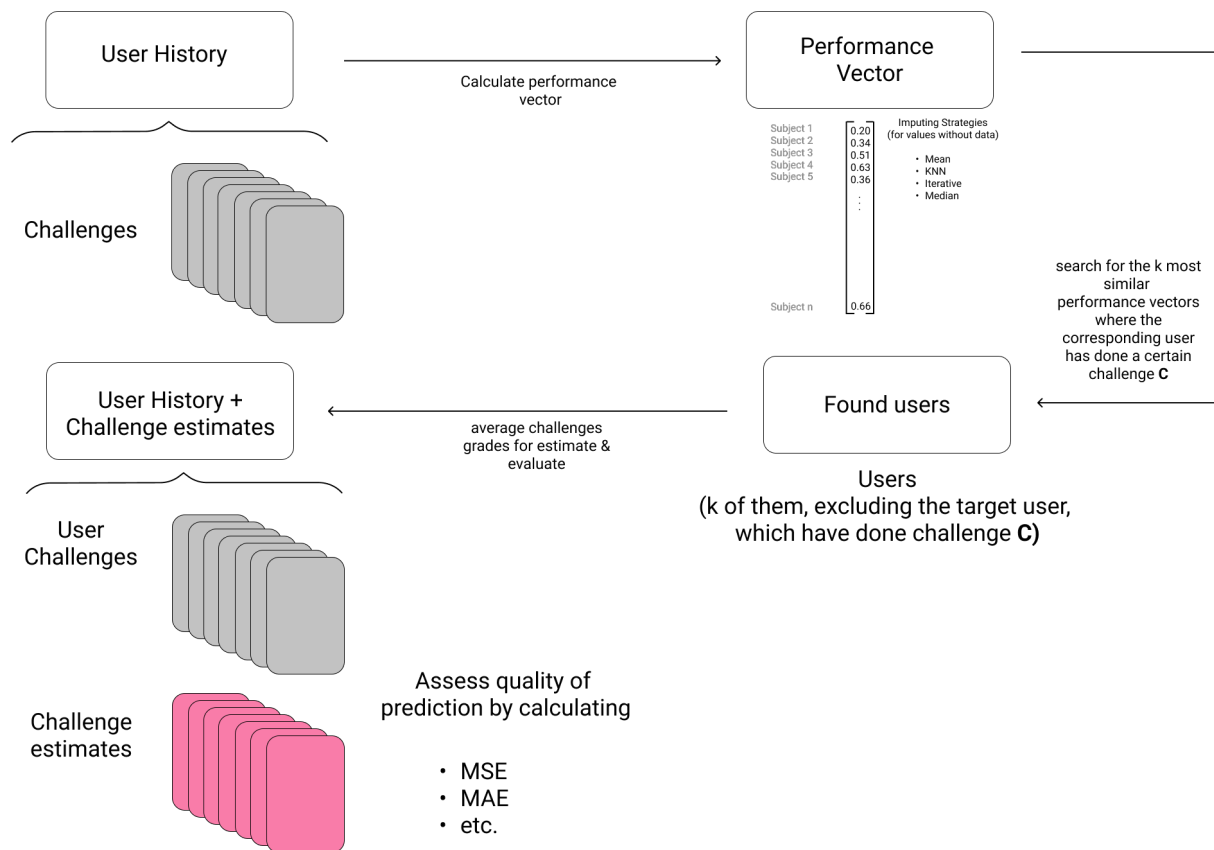


Figure 3. Assessment framework for grade estimation.

At initial stage, we calculate performance vectors for the entire dataset, encompassing all users. This computation is parameterized by the imputation strategies. Using the performance vectors obtained in the initial stage, we proceed to identify a set of users closely situated to the target user. The objective is to determine a balance that avoids underfitting, which occurs when k is too low. Conversely, opting for a higher k may result in overfitting, where the model becomes excessively tailored to users who are inherently distant from the target. We iterate through the process of grade estimation for each challenge previously undertaken by the user, generating outcomes that serve as input for the final stage. To assess the similarity between the real and predicted performance, we have chosen to employ two distinct metrics, namely, MSE and MAE.

Figure 4 depicts the outcomes of the grade estimation utilizing both MSE and MAE.

In the process of computational experiments, the influence of clustering parameters on the accuracy of grade prediction was investigated. The impact of imputation strategies, Mean, Median, kNN, and Iterative Imputation, was also analyzed. Upon examining the results, it is evident that predictions obtained are quite accurate.

8. Conclusions

Considering the outcomes presented in the paper, it is evident that we have successfully achieved our objectives. In future work, we recommend revisiting the grade estimation framework to refine the computation process. While averaging serves as a good starting point, it may fall short of fully incorporating additional knowledge, leaving room for further enhancements. Replacing the mean computation with a weighted kNN approach might already improve the whole system.

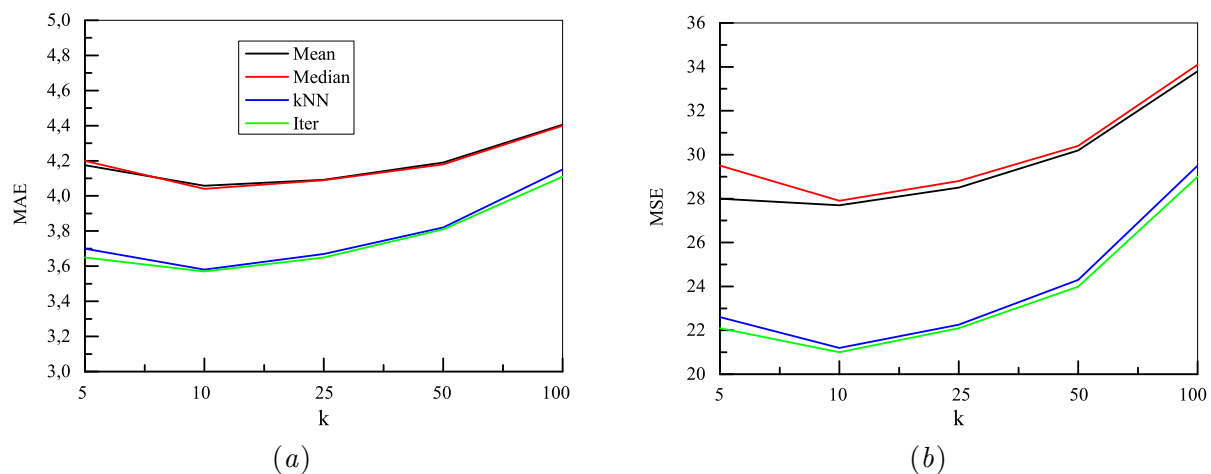


Figure 4. Results of the grade estimation assessment for MAE (a) and MSE (b) for $n = 512$.

We also recognize opportunities for improvements in the non-functional performance of the system. While the grade estimation process, taking approximately 600 ms, is not considered slow for a recommendation algorithm, real-time usage may benefit from additional optimizations. Implementing caching mechanisms or refining the database querying process could potentially enhance the system's responsiveness, making it more efficient for real-time utilization. Moreover, integrating timing constraints could make the system more realistic for practical applications.

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Virtual educational mathematics park as a platform for educational and research activities at the university

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Abstract. The article is devoted to the problems of creation and functioning of an educational mathematical park as an innovative platform for student research within the university environment. Mathematical parks are considered as unique spaces that combine scientific knowledge with aesthetic aspects, transforming mathematical concepts into interactive exhibits and art objects. The analysis of research papers and resources containing materials about modern science parks allowed the study to prove that the virtual educational mathematics park is a platform for the teaching and research activities of university teachers and students. The review of thematic publications is the basis for defining the conceptual and categorical apparatus and analysis, systematizing and summarizing existing experience, substantiating the theoretical foundations of the study, developing and implementing the author's ideas. The article summarizes the definition of math parks and classifies them. The authors have identified two main types: landscape (real) and virtual educational math parks. Among virtual parks, the authors focus on two subcategories: 3D modeling and 3D printing, and virtual math laboratories. The potential of innovative approaches (landscape mathematical parks and virtual laboratories) to popularize mathematics among young people through the use of interactive teaching methods and applied research at the intersection of mathematics and computer science is studied. The types and didactic possibilities of virtual mathematical educational laboratories are described. The authors presented in the article two of their own projects, "Platonic Solids Mathematical Park" and "3D Modeling and its Use for Limb Prosthetics", which took part in the competition "Budget of Public Initiatives of Vinnytsia City United Territorial Community" (Vinnytsia, Ukraine), one of which won the competition and was implemented. The article investigates the specifics of using virtual mathematical laboratories in the process of training bachelors of mathematics. The author's mathematical sites created and implemented as virtual laboratories are one of the platforms for teaching and research activities at the university, meet the main criteria for the successful functioning of virtual educational mathematical parks: strategic focus, complexity, intensity, structuredness, connectivity and mobility. The authors' idea allows us to harmoniously combine the past and the present: to visualize the outstanding achievements of mathematics by means of modern achievements in the use of digital technologies in education.

1. Introduction

The role of mathematics in the life of every person is undoubtedly enormous. It has always been of undeniable cultural and practical importance, and its role in the technical and economic development of society is hard to overestimate. Today, everyone should realize that mathematics



is an effective tool for modeling and studying the processes and phenomena of the surrounding reality, a basic component of general and vocational education of a modern person, an effective means of developing thinking, spatial imagination, scientific outlook of a person, and an integral part of human culture. High-quality mathematics education is a prerequisite for successful mastery of a number of specialties important for the economy and society.

The results of the national multi-subject test in Ukraine and the Program for International Student Assessment (PISA) show that there are problems in mathematics education in many high-income countries [1]. Various external factors add to the urgency of this problem: global epidemics, armed conflicts, environmental and economic problems. Therefore, scientists and teachers in the educational systems of states are learning to respond quickly to changes in the external environment, in particular, the organization of the educational process in remote and blended formats using digital technologies and virtual interactive opportunities to present a variety of educational content [2,3].

A number of high-income countries pay considerable attention to the popularization of mathematics, including the creation of so-called science parks. Among the science parks, we would like to highlight math parks as amazing places to walk, where science is intertwined with art and nature. They invite us to a kind of museum to look at familiar things from a new angle and discover a fascinating world where the exhibits are mathematical formulas, theorems, and objects. It is also an interactive space where visitors can explore mathematical concepts through art, games, and installations.

Among the most famous and visited parks are the Ontario Science Center in Toronto [4], the National Museum of Mathematics (MoMath) in New York [5], the Participatory Museum Do Not Touch Forbidden in Buenos Aires [6], the Chicago children's museum on Lake Michigan [7], A Museum for Mathematics in Priverno [8], the Archimedes Garden: A Museum of Mathematics in Florence [9], Mathematical center Mathematikum in Giessen [10], The first state "Science Museum" of the Small Academy of Sciences of Ukraine in Kyiv [11], a mathematical park created in honor of the famous mathematician Srinivas Ramanujan in India [12].

Modern technologies open up new opportunities for teaching and popularizing science. A striking example of this accessibility is virtual tours of math parks. Students from different parts of the world can visit the most famous math parks at the same time without spending money on travel and accommodation. In addition, virtual tours can be conducted at any convenient time, which ensures individualization of the educational process.

Visitors to virtual tours are immersed in the world of mathematics from the comfort of their own homes. Thanks to interactive elements such as 3D models, panoramic images, and videos, students can visualize complex math concepts and see how they translate into real-world objects. This contributes to a deeper understanding of the material and increases motivation to learn math. Interactive elements of virtual tours make learning more interesting and effective. Students can explore the exhibits, answer questions, and complete tasks on their own, which helps develop their critical thinking, creativity, and independent work skills.

Virtual tours of math parks are also a powerful tool for popularizing science. They demonstrate that mathematics is not only a set of abstract formulas, but also a beautiful art that surrounds us in everyday life. This helps to overcome stereotypes about math as a difficult and boring science.

Part of the virtual parks are virtual laboratories that diversify the educational toolkit with numerous illustrative and creative presentation opportunities. Spectacular interactive elements and embedded applications help develop research skills, facilitate the preparation and implementation of student projects, help students learn the material easier and better, and arouse their interest in science. Virtual laboratories are also an indispensable tool for STEAM education, allowing students to create their own mathematical models [13–17].

Virtual laboratories are emerging as a tool to support distance education and are a resource

for teaching and learning that ensures the achievement of learning outcomes, allows for the confirmation of knowledge gained by students, and assists the instructor in teaching the course [18].

The article by Tsviakh et al. [19] explores the use of virtual laboratories at the university to increase students' interest and professional competence. The author discusses the didactic potential of virtual laboratories, their types and advantages in the educational context. The study emphasizes the innovative nature of virtual laboratory work and its contribution to skills development and research. The results demonstrate that virtual laboratories are effective in increasing motivation, building professional skills, and promoting student engagement in research. The study concludes that the integration of virtual laboratories into higher education curricula is crucial for training future professionals in an increasingly digital world.

Virtual laboratories can be offered as an alternative solution when access to a physical laboratory may be limited. Therefore, virtual laboratories can be used either as primary resources or as support systems for students' laboratory activities. To identify the goals, technologies, and benefits of virtual laboratories, Triejunita et al. [20] conducted a systematic literature review of articles on virtual laboratories from 2016 to 2021. This article summarizes six purposes, five types of technologies, and seven benefits of virtual laboratories. Based on the results of the study, the use of virtual laboratories has increased student motivation and engagement in learning, and improved student learning outcomes.

The experience of combining software tools to create a virtual laboratory as an alternative to a real one is presented by Zayas-Gato et al. [21]. The proposed modern simulation environment provides students with an online working tool suitable for applying engineering control concepts using a new approach in the Blended Learning methodology. This combination of personal experience and online technologies is an effective approach in the modern educational context.

Kapilan et al. [22] discussed the basics of virtual laboratories, their different types and impact on student learning, opportunities and limitations of virtual laboratories.

Hassan et al. [23] examined the use of virtual laboratories and their usefulness in the higher education sector through the lens of learning theories to understand their features and benefits using different virtual laboratories approaches, hardware and software settings.

Yusuf and Widyaningsih [24] investigated the implementation of an e-learning-based media virtual laboratory for students' metacognitive skills.

The aim of the study by Aboraya [25] was to assess the learning of abstract mathematical concepts by fifth grade students in a blended learning environment supplemented by a virtual web laboratory. The results showed a clear positive impact on improving students' achievement in abstract mathematical concepts in favor of the experimental group. Students were found to be very favorable to using the simulation website.

The results of the study by Lestari and Supahar [26] show that most students need to develop virtual laboratory media to support the media for scientific and practical activities. This condition was confirmed by the interview, teachers suggest that with the help of a virtual laboratory that has materials, videos, images, and simulations, students not only understand the theory, but can also perform practical activities virtually. The teacher argues that it is necessary to develop a virtual laboratory to overcome the limitations of the science workshop in schools because students and teachers need a virtual laboratory to learn science.

The purpose of the article is to search for and study the possibilities and conditions for the creation, development and functioning of landscape mathematical parks and virtual educational laboratories to popularize, motivate the study and practical application of knowledge in mathematics education through the implementation of applied research in mathematics and computer science through innovative resources.

A thorough analysis of research papers and resources containing materials about modern science parks allowed the study to prove that the virtual educational mathematics park is a

platform for educational and research activities at the university. Consideration of publications devoted to the issue under study in periodicals of philosophical, psychological, pedagogical and methodological orientation is the basis for defining the conceptual and categorical apparatus and analysis, systematization and generalization of existing experience, substantiation of the theoretical foundations of the study, development and implementation of the author's ideas.

2. Conceptualization and research studies

In the educational space of bachelor's and master's degree in mathematics, let's pay attention to the formation and creation of the so-called mathematical park. The Great Explanatory Dictionary of the Modern Language interprets the word "park" as "a large garden for special purposes, usually open to visitors" [27]. The team of authors understands the term "mathematical park" to mean a natural or virtual area with a prepared infrastructure that demonstrates the connection between mathematics and nature and society. The main purpose of creating a mathematical park is to show that mathematics is the basis of the laws of nature and society, to evoke not only positive emotions of visitors, delight, surprise and enjoyment of mathematical objects, but also the desire to study mathematics.

We will divide the math park into two interconnected parts: a landscape math park and a virtual educational math park (figure 1).

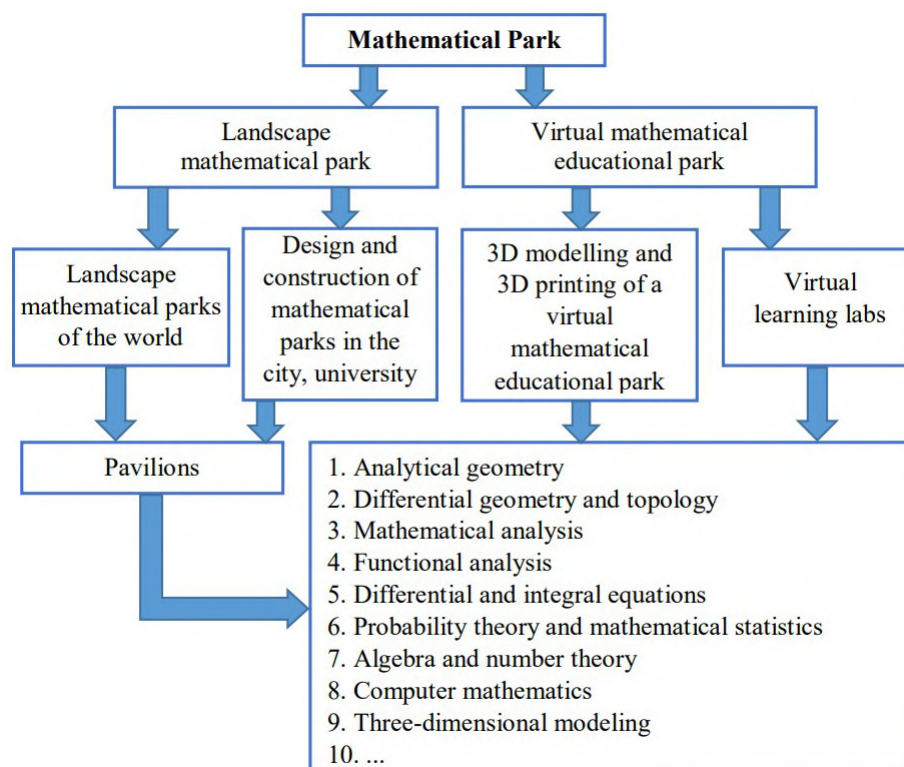


Figure 1. Structural model of designing and modeling mathematical parks.

We understand that the implementation of large-scale landscape projects requires significant investments. Studies show that relatively few such parks have been created on the planet.

The main task of landscape museums is to popularize science. Not just to say that science is important, but to show that it is fun, interesting, and there are many opportunities for self-realization in education and science. This completely changes the attitude towards science centers and creates a culture in which science is truly of great value.

Museums of mathematics explain complex phenomena using simple objects as examples, showing how discoveries, formulas, and fundamental research are related to everyday life. You can interact with each exhibit. Museums organize traveling exhibitions, educational newsletters, and educational classes.

The authors of the article propose to create a mathematical landscape park or part of it in a city or university. In 2020, we developed the so-called Big Project “Platonic Solids Mathematical Park” and took part in the competition “Budget of Public Initiatives of Vinnytsia City United Territorial Community” (Vinnytsia, Ukraine) [28]. This project is a unique mathematical art object with green spaces and universal color lighting. It harmoniously combines an architectural complex of five regular polyhedra, saturated with various creative elements of public space. These polyhedra have special QR codes and information support, which will allow residents and visitors to visualize information about this object in several languages using digital technologies (figure 2).

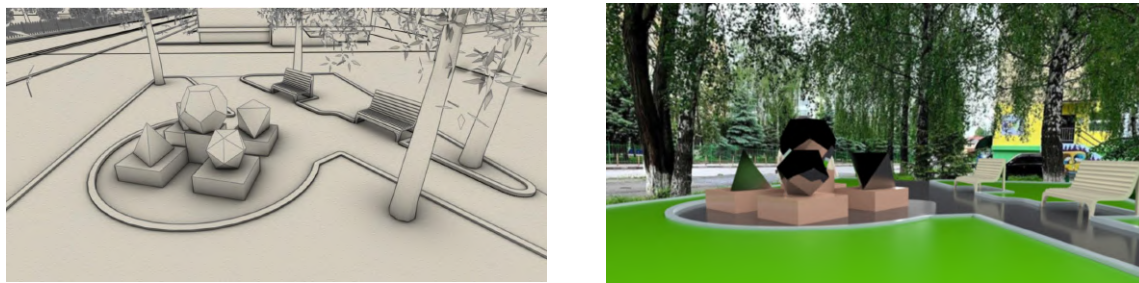


Figure 2. 3D model of the Platonic Solids Mathematical Park.

The implementation of such a project will be an important component in ensuring the integrated development of any territorial community and will help create a city where young people, professionals, scientists, business, and tourists want to stay.

The creation of a landscape mathematics park in the city where a modern educational center is located has many advantages: increasing the attractiveness of the city for educational tourism; meeting the needs of young people for open cultural and educational spaces; popularizing mathematics among residents and visitors; creating a creative and creative environment in the city; visualization of small architectural forms of public space using digital technologies; increasing the attractiveness of the city for carriers of new ideas, experience and knowledge; a calm cozy corner appears that will serve as a place of rest and aesthetic pleasure for residents.

As a result of the meeting of the competition’s expert group, our project received a positive assessment and was allowed to vote. As a result of online voting, the project was supported by 477 people, so it has not yet been implemented. Given the quarantine restrictions, in 2020, Vinnytsia residents could support projects exclusively electronically using the Public Budget e-service.

Another area of popularization of math parks is the creation of virtual math educational parks using 3D modeling and 3D printing and virtual learning laboratories with a large number of pavilions (figure 3).

3D modeling and 3D printing of the virtual mathematical educational park implements the visual and interactive component of student learning at the university. Virtual three-dimensional mathematical models can be rotated, moved, and scaled in digital 3D space. In the process of working with the model, students learn the basic ways to create and work with three-dimensional models. In three-dimensional modeling programs, you can design objects based on primitives, polygons, NURBS curves, Bezier curves, metasphere, Boolean operations, and Subdivision Surface. It is possible to download the created mathematical 3D model for texture

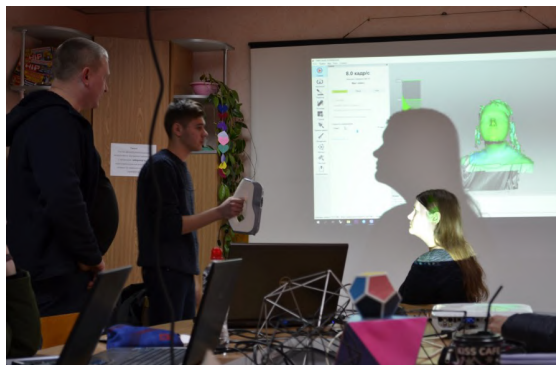


Figure 3. Create a 3D model by 3D scanning.



Figure 4. A 3D printed Klein's bottle.

editing, create animation, or print it on a 3D printer (figure 4). Students acquire professional competencies in working with three-dimensional modeling programs to create mathematical models.

Another interesting project organized by the authors of the article is “3D Modeling and Its Use for Limb Prosthetics” [29]. This so-called Small Project was submitted to the “Budget of Public Initiatives of the Vinnytsia City Amalgamated Territorial Community” competition in 2020. According to the results of the meeting of the Expert Group of the competition, our project received a positive assessment and was admitted to the citywide vote. As a result of the online voting, the project was supported by people, recognized as the winner, and implemented in 2021. Today, the creation of 3D models is an indispensable process not only in industry but also in many areas of human activity, such as medicine, architecture, construction, design, education, etc. Making 3D models allows you to evaluate the technical and physical features of the modeling object before creating its real sample. The main goal of this project is to design and manufacture prostheses based on 3D modeling, to conduct a series of popular lectures on 3D modeling for residents of the territorial community, which will bring education and research closer to the social needs of community residents and to implement the principles of the UN Convention on the Rights of Persons with Disabilities at the local level (figure 5). An inclusive city policy should promote full and equal participation in the lives of all citizens, take into account the needs (interests) of everyone as much as possible, creating a comfortable city for all residents without singling out a particular category. The developments in 2022-2025 in Ukraine have shown that this type of project is particularly relevant in the context of martial law.

The ideas and principles underlying the Small Project will have a positive impact on the formation of Vinnytsia as a city of social cohesion. The project is in line with the main priorities and objectives of the Vinnytsia 2030 Integrated Development Concept in the vision “Comfortable, Cultural and Socially Responsible City” [30]. The vision envisages participation in social assistance activities aimed at promoting, protecting and ensuring the full and equal enjoyment of all human rights and fundamental freedoms by people with functional disabilities (people who have lost limbs), creating inclusive spaces and accessibility; expanding the activity and independence of people with disabilities in various spheres of life; introducing modern practices of providing rehabilitation services in the city and disseminating them at the regional and national levels.

An important feature of the Small Project is the involvement of non-governmental



Figure 5. A series of popular lectures on 3D modeling.

organizations and volunteers in solving these problems, training them to provide qualified assistance to people who have lost limbs.

The practical value of the Small Project “3D modeling and its use for limb prosthetics” is to hold a Creative Competition in 3D modeling among residents of the Vinnytsia City United Territorial Community, create conditions for the development of the intellectual potential of community residents, support scientific and creative work, stimulate the interest of community residents in research, and master innovative technologies [31].

The creative competition consisted of two rounds (part-time and full-time) held in November–December 2021. For the correspondence round, the contestants had the opportunity to submit a work (3D model) in accordance with the specified topics and requirements specified in the Contest Regulations. The jury developed criteria for evaluating the entries. A total of 15 works were submitted for the correspondence round, among which the jury selected the best 8 works to participate in the on-site round. The in-person round was held on December 14, 2021, at the NotBox educational hub of Vinnytsia Mykhailo Kotsiubynskyi State Pedagogical University. The participants of the Competition demonstrated profound knowledge and practical skills in 3D modeling, which confirmed that the Vinnytsia City Amalgamated Territorial Community has talented young people capable of mastering new technologies, building and implementing models using modern engineering (figure 6).

Another area of implementation of virtual mathematical educational parks (figure 1) is the creation of virtual educational laboratories.

Modern scientists have different interpretations of the concept of “virtual laboratory” (virtual laboratory, VLab, virtual reality laboratory):

- a virtual learning (educational) environment that helps in acquiring new knowledge and skills, allows to model the behavior of real-world objects in a computer environment and serves as a research tool for various natural phenomena with the possibility of building their mathematical models [32–34]. In other words, a virtual laboratory is a special computer system that allows you to reproduce various experiments or studies using software and modeling of virtual environments. The advantages of such laboratories cannot be overestimated in the context of blended and distance learning. The main advantage of virtual laboratories is the ability of participants in the educational process to perform various studies without leaving their personal computers. At the same time, this makes it possible to spend time and resources efficiently, which in turn affects the level of knowledge and competence of students [34];
- a technological tool that allows students to contribute to problem-based learning (PBL) and synthesize ideas, develop a learning network and solve any real business problem using theoretical knowledge, establishing connections between ideas embedded in the network [23];

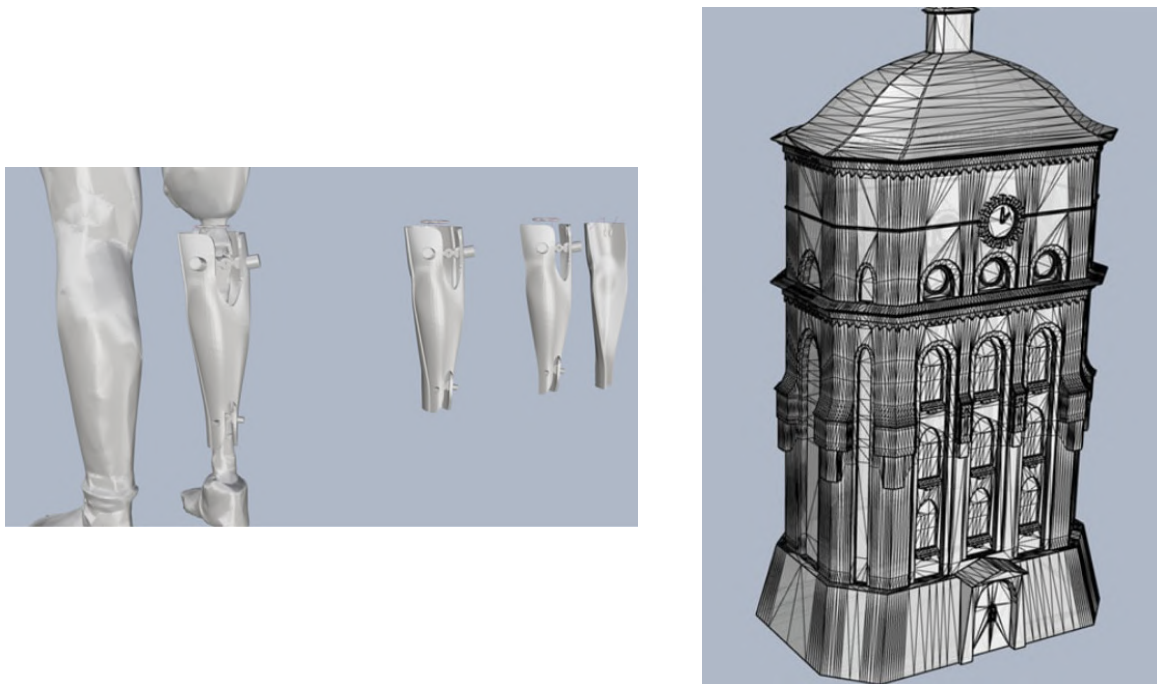


Figure 6. Creative competition in 3D modeling, December 2021.

- an educational technology that “allows modeling the behavior of real-world objects in a virtual computer-based educational environment and helps students to acquire new knowledge and skills” [35,36];
- a type of computer program that facilitates modeling on computer processes [37];
- a computer platform or program that enables students, interested parties, and scientists to perform experiments in the biological sciences and to virtually model, observe, and study phenomena that occur in real laboratories [38];
- a software virtual environment in which the possibility of studying the behavior of object models and their derivative sets, specified by real objects with a certain level of detail, within a certain field of knowledge is organized [39].

Thus, we define a virtual learning mathematics laboratory as a virtual educational environment of a university where a student, under the guidance of a teacher, learns to model real or imaginary objects, analyze them, synthesize new ideas using computer mathematics systems and other technological tools. Didactic capabilities of virtual mathematical educational laboratories:

- the use of dynamic and interactive learning environments through the integration of audiovisual elements, hypertext, animation form the professional competencies of a bachelor of mathematics;
- individualization of the educational process, the student can work at a pace that satisfies him or her and focus on those points that are most important for him or her in professional growth;
- computer modeling skills, application of computer mathematics systems;
- development of student’s creative thinking and research competencies, ability to make prompt and independent decisions;
- obtaining quality education;

- the use of digital educational technologies in the virtual learning environment contributes to the democratization of access to quality mathematics education, allowing students to acquire the necessary knowledge and skills, regardless of geographical location.

We classify the types of virtual mathematical educational laboratories using the results of research [38]:

1. Virtual laboratories in which students carry out research projects, build surfaces, and interact with three-dimensional stereometric shapes, in particular on the resource <https://www.mozaweb.com> [40], platonic solids that can be rotated, scaled, and viewed at <https://polypad.amplify.com/p#solids> [41].
2. Virtual laboratories that allow conducting numerical experiments using computer mathematics systems with programming elements, software for processing 3D graphics.
3. Virtual laboratories based on digital measurement technologies, 3D scanning, 3D modeling and 3D printing.
4. Virtual laboratories with augmented or virtual reality.

The authors of the article consider it expedient to create virtual learning laboratories in universities for analytical and differential geometry and topology, mathematical and functional analysis, differential and integral equations, probability theory and mathematical statistics, algebra and number theory, computer mathematics, three-dimensional modeling, etc. in the training of bachelors of mathematics (figure 1). After all, there are great opportunities for students' educational and research activities, in particular, modeling solids in space, calculating surface areas, volumes, solid mass, center of mass, and other physical quantities. During the course of study, students can create their own bank of lines and surfaces (figure 7).

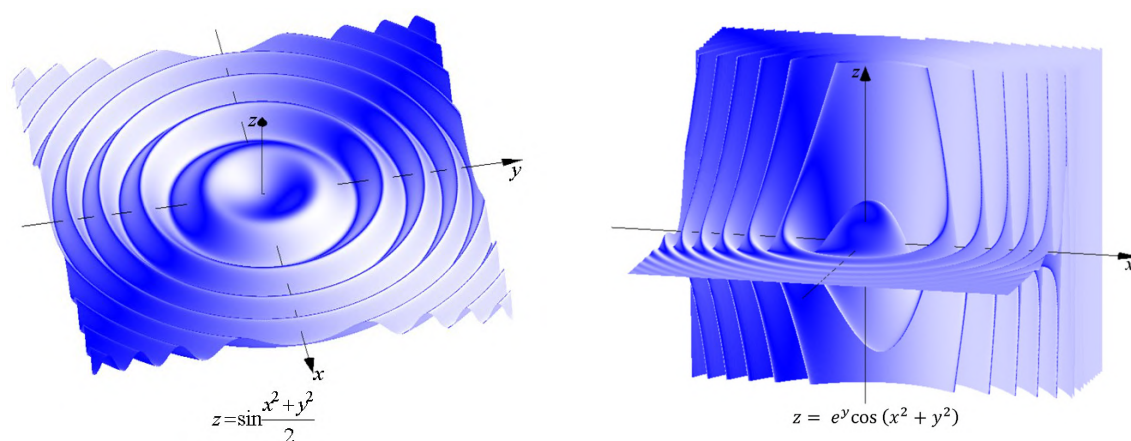


Figure 7. A bank of surfaces created in a virtual laboratory when studying the function of many variables.

For example, here is a problem of calculating the volume of a solid.

Task. Calculate the volume of the solid bounded by the surfaces $y = 1 + x^2 + z^2$ and $y = 5$.

The solid is bounded by a paraboloid of rotation about the axis O_y and a plane $y = 5$, perpendicular to the axis O_x (figure 8). Its projection on the plane O_{xz} is a circle bounded by the circle $x^2 + z^2 = 4$.

Let's determine the volume of our paraboloid:

$$\begin{aligned}
 V &= \iiint_D (5 - 1 - x^2 - z^2) dx dz = \left| \begin{array}{l} x = \rho \cos \varphi \\ y = \rho \sin \varphi \\ J = \rho \end{array} \right| = \iint_D (4 - \rho^2) \rho d\rho d\varphi \\
 &= \int_0^{2\pi} d\varphi \int_0^2 (4\rho - \rho^3) d\rho = 2\pi \left(2\rho^2 - \frac{\rho^4}{4} \right) \Big|_0^2 = 8\pi \approx 25,132 \text{ (cubic units)}.
 \end{aligned}$$

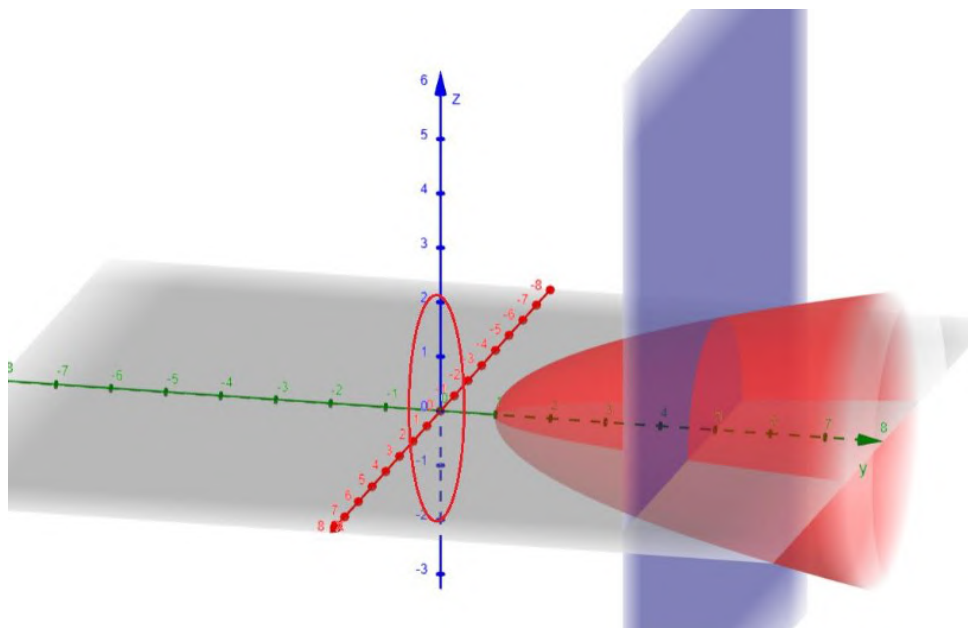


Figure 8. Structural model of designing and modeling mathematical parks.

Let's determine the volume of our paraboloid

In differential equations, students are offered the project "Approximate methods for solving the Cauchy problem". One of the tasks of the project is to construct a field of directions and isoclines of a differential equation. Here are several ways to accomplish this task using computer mathematics systems (figure 9, figure 10).

After completing such projects, students learned how to: apply approximate methods for finding a solution to a first-order differential equation, analyze and compare them, determine the error of calculations, draw isoclines and the field of directions using different software.

We also practice holding a scientific and methodological seminar "Interesting Geometry" as part of the study of the geometric disciplines "Analytical Geometry", "Constructive Geometry", "Fundamentals of Geometry", "Non-Euclidean Geometry" and "Additional Sections of Geometry". During the meetings, higher education applicants presented and defended their individual projects on various topics: "Regular polyhedra", "Klein's bottle", "The Möbius strip" (figure 4, figure 11), "Album of second-order lines given in the polar coordinate system", "Problems on combinations of spatial solids with a sphere", "Problems on the construction of spatial solids and their sections" etc. Having visualized the results of research on their chosen topics through interactive presentations and videos, graphs and diagrams, their own stereometric models of regular polyhedra, etc.

At the same time, they demonstrated a high level of mathematical training, analytical thinking and creative approach to the disclosure of topics, ingenuity and resourcefulness. Of

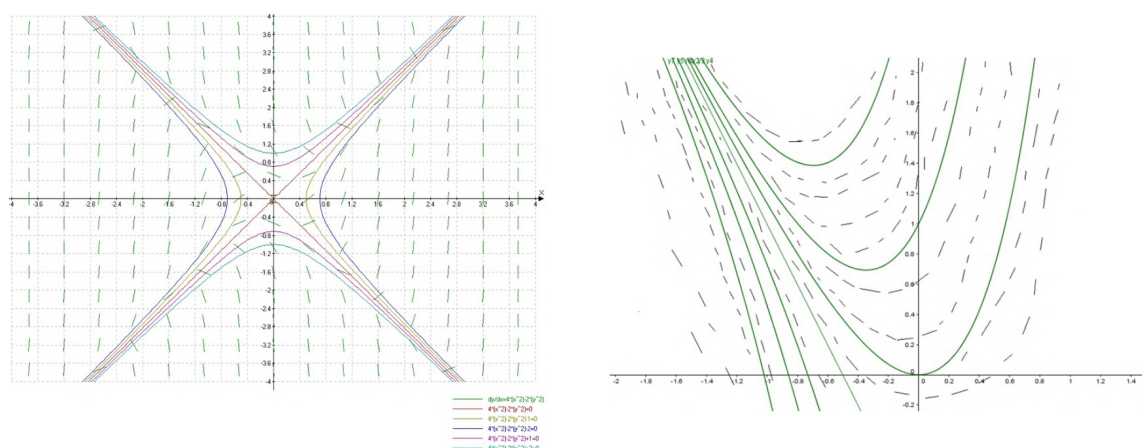


Figure 9. Isoclines and the field of directions of differential equations (student projects).

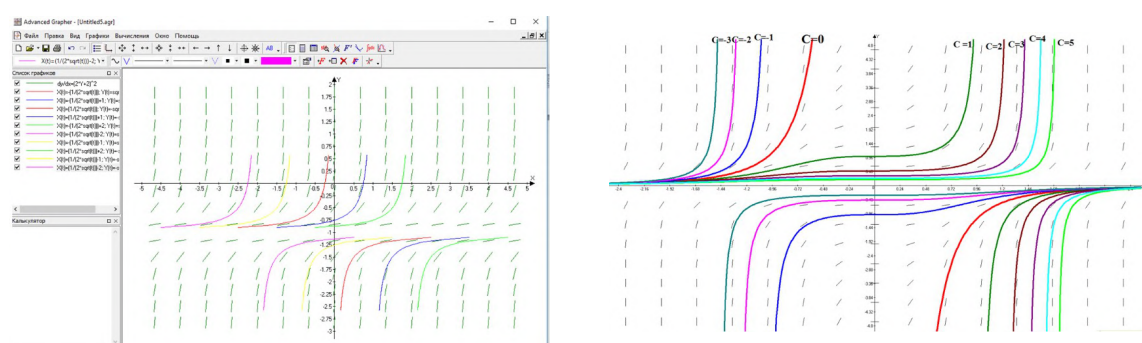


Figure 10. Isoclines and the field of directions of differential equations (student projects).

particular interest and enthusiasm were the integrated projects that combine geometry with other mathematical disciplines, as well as with various fields of activity, such as architecture, art, engineering, etc.

The purpose of these projects is not only to test the theoretical knowledge of students, but also to develop practical skills in solving various problems and applying them in real-life situations, to popularize mathematical knowledge, and to reveal the main mathematical features of mathematical disciplines.

Such events increase interest in studying mathematical disciplines; expand opportunities for the development of mathematical competence of students; activate their cognitive activity; create a platform for active exchange of ideas; improve the general culture of students and develop their ability to communicate with others; promote the development of public speaking skills, teamwork and the formation of scientific thinking, the ability to use digital technologies (figure 11).

The authors of the article propose to create a unique learning space – a mathematical park, where real models of geometric bodies are supplemented by virtual interactive elements. At the first stage, this project involves students creating 3D models under the guidance of teachers. At the second stage, the best three-dimensional models will be printed on a 3D printer and placed on the university campus. Each exhibit will be accompanied by a QR code that will redirect the visitor to a webpage with detailed information about the corresponding geometric solid. As part of the project, students will take part in the creation of an innovative educational mathematical park of miniatures of spatial solids.

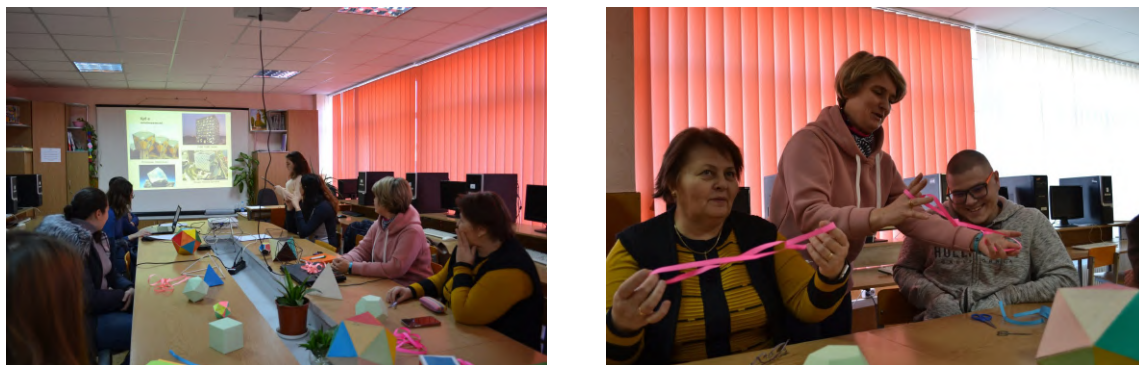


Figure 11. A scientific and methodological seminar “Interesting Geometry”.

As one of the ways to organize virtual educational mathematical laboratories, we see the use of a teacher’s personal website in the educational process. The teacher’s website <https://www.kovtonyuk.inf.ua/> [42], created by Mariana Kovtoniuk 12 years ago, has a standard list of materials for this type of structure: news; an electronic manual (for independent study of theoretical and practical material, created on a hypertext basis, which allows students to work on an individual educational trajectory); a file section (here, users of the site can access additional educational materials); exhibitions (an opportunity to showcase the best student educational or research projects); information about the curators of the project as a whole and individual sections; a gallery of photos from conferences, competitions, Olympiads, defense of qualification works, etc. [43].

3. Conclusions

The article discusses the problems of developing and implementing an educational mathematical park, which is a component of a mathematical park, as a platform for teaching and research activities of teachers and students at a university. Mathematical parks are amazing places to walk where science is intertwined with art and nature. They invite us to a kind of museum to look at familiar things from a new angle and discover a fascinating world where the exhibits are mathematical formulas, theorems, and objects. It is also an interactive space where visitors can explore mathematical concepts through art, games, and installations.

The authors define mathematical parks, classify them into landscape and virtual educational mathematical parks, and highlight 3D modeling and 3D printing and virtual mathematical laboratories among the latter.

The possibilities and conditions for the creation, development and functioning of landscape mathematical parks and virtual educational laboratories for the popularization, motivation of study and practical application of knowledge in mathematics education through the implementation of applied research in the field of mathematics and computer science through innovative resources are investigated. The types and didactic possibilities of virtual mathematical educational laboratories are indicated.

The authors presented in the article two of their own projects, “Platonic Solids Mathematical Park” and “3D Modeling and its Use for Limb Prosthetics”, which took part in the competition “Budget of Public Initiatives of Vinnytsia City United Territorial Community” (Vinnytsia, Ukraine), one of which won the competition and was implemented.

The features of virtual mathematical laboratories in the training of bachelors of mathematics are considered. It is shown that the functioning of such laboratories ensures the formation of not only the mathematical culture of the future specialist, but also the formation of such basic competencies as the ability and willingness to self-study, application of knowledge, skills and

abilities to work with computer mathematics systems with programming elements to improve the efficiency of education, self-education and professional activity. The developed and implemented author's sites in mathematics as virtual laboratories meet the main criteria for their effective functioning: strategic focus, completeness of coverage, intensity, orderliness, connectivity and mobility.

The authors' idea allows us to harmoniously combine the past and the present: to visualize the outstanding achievements of mathematics by means of modern achievements in the use of digital technologies in education.

We see prospects for further research in the creation of a virtual educational mathematical park as a platform for educational and research activities at the university; in the construction of a landscape mathematical park of miniatures printed on a 3D printer and its information support on the territory of the university; studying the impact of student participation in virtual laboratories on the formation of their mathematical, informatics and pedagogical culture.

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Multifactorial analysis of mobbing behavioral signs in educational environments posts by NLP means

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Abstract. Paper proposes approach to solving the problem of automatic mobbing detection in educational environments. Proposed method for multifactorial analysis of mobbing behavioral signs in educational environments posts by NLP means consists of number of stages, including text pre-processing, sentiment analysis, named entities recognition and grouping them by mention frequency. Developed mathematical model of mobbing reveals set of factors, such as aggregate sentiment towards each person, mentions frequency, negative mentions intensity, and overall sentiment, which allows for objective assessment of mobbing manifestations in texts, on which basis the psychological violence level in teams can be determined. The detection of these parameters provides an explanation of the mobbing detection process. The implemented approach has important practical significance for the automated detection and assessment of aggressive behavior in online environments. Method is suitable for automatic mobbing detection in various contexts, in particular, educational environments, social networks, corporate environments, professional communities etc. Applied use results of proposed method revealed average correlation 95.99% with expert opinions, which shows possibility of high-quality automating the mobbing detecting process in educational environments.

1. Introduction

In modern educational institutions, digital interaction has become a key aspect of educational process, but at the same time, such interaction creates new challenges in the form of mobbing, in particular through online platforms. Identifying and analyzing such manifestations is extremely important, as they can significantly affect the psycho-emotional state of participants in the educational process, reducing its effectiveness and creating a toxic atmosphere [1,2]. The problem of mobbing in educational environments is one of the most pressing social topics, which causes significant concern among educators, psychologists and researchers. In educational and digital environments, mobbing is interpreted as “repeated aggressive behavior directed at a person or group of people with the aim of causing them psychological harm, isolation or humiliation”. The main characteristics of mobbing are duration, repetition, imbalance of power between the aggressor and the victim, as well as emotional and social consequences for the victims [3].

Using NLP methods to analyze text data in social networks, forums, and other platforms allows you to automate the detection of signs of mobbing. This becomes especially important in large educational communities, where manual monitoring is ineffective. Thanks to such approaches, you can identify aggressive behavior patterns, determine the context of conflicts,



and prevent their escalation [4,5]. Given the high level of digitalization, such studies contribute to the implementation of preventive measures and the formation of a safe educational environment. The introduction of natural language processing tools contributes not only to the improvement of the psychological climate, but also to the formation of sustainable digital competencies in society. In combination with modern big data analysis technologies, this allows you to create more effective mechanisms for resolving social conflicts in educational institutions [6].

Mobbing detection in educational environments is important step towards ensuring the safety and well-being of participants in the educational process, which directly contributes to the achievement of several Sustainable Development Goals (SDG) approved by UN. First of all, it contributes to the achievement of SDG No. 4 “Quality Education” [7], as bullying creates hostile atmosphere that negatively affects the motivation to learn, academic performance and emotional state of students. Identifying and preventing bullying helps to create an inclusive, safe and supportive learning environment where each participant has equal opportunities for development. Identifying mobbing also contributes to SDG No. 3 “Good health and well-being” [8], as mobbing can cause serious psychological consequences, such as anxiety, depression or low self-esteem, in participants in the educational process. In addition, addressing the problem of identifying mobbing contributes to the achievement of SDG 16 “Peace, justice and strong institutions”, which aims to prevent violence and create peaceful and inclusive societies [9]. Bullying-free educational environments contribute to the formation of trust, mutual respect and equality, which are important elements of sustainable society.

The study meets global challenges in the education field, aimed at ensuring inclusiveness and creating favorable conditions for personal development. The use of NLP in such an area is a promising direction that contributes to integration of technologies into socially important processes.

The purpose of study is to create method for multifactorial analysis of mobbing behavioral signs in educational environments posts by NLP means, which allows not only to detect the presence of such signs, but also to analyze their intensity and direction.

The main contribution of the paper is proposed method for multifactorial analysis of mobbing behavioral signs in educational environments posts by NLP means, which allows providing justified explained solutions and can be adapted for different areas by changing the threshold values of the influence of behavioral signs.

2. Related works

Mobbing includes not only physical or verbal violence, but also cybermobbing, which is becoming increasingly popular in the context of the globalization of digital communications in work teams [10]. Research shows that mobbing can have severe psychological consequences for victims, as online bullying is often accompanied by a lack of security, anonymity and the rapid spread of information among work colleagues and outsiders [11]. Mobbing often manifests itself in educational environments, as they are open spaces for interaction between teachers, pupils and students of all ages. It is this constant communication and multi-level structure of communication that create the conditions for the emergence of conflicts that can develop into forms of bullying [12].

Although the mobbing problem is attracting increasing attention from the scientific community, there remains relatively little research dedicated to the mobbing detection. This is especially true for analysis of text data in the context of educational environments. This is due to the lack of large volumes of labeled data that could be used to train neural networks, as well as the multifactorial nature of concept of mobbing itself. However, given that mobbing is type of cyberbullying, works in this area has much in common with the topic of mobbing, since both phenomena are characterized by the use of text content for bullying, aggression or manipulation.

Ma [13] proposed an ensemble transformer architecture to predict whether respondent is being

bullied by transforming text data into underlying emotions. The paper proposes an approach to text data analysis that is based on detecting emotional patterns, such as frequent use of words related to anger or sadness, as these emotional signs can signal the risk that a student may be a victim or aggressor of bullying.

Nuthalapati et al. [14] analyzes machine and deep learning approaches to detect cyberbullying. Among the evaluated models, such as Random Forest, XgBoost, Naive Bayes, SVM, CNN, RNN and BERT, the highest results were achieved using the BERT model, which demonstrated an accuracy of 88.8% in binary classification.

Gowthami et al. [15] presented the model for detecting cyberbullying based on deep learning and natural language processing techniques. Data from Twitter, Instagram and Facebook were used for the analysis, which were processed using the long short-term memory algorithm. The model showed high efficiency in detecting cyberbullying cases, surpassing previous approaches. The achieved accuracy indicators for different platforms were: Twitter – 96.64%, Instagram – 94.49%, Facebook – 91.26%, which emphasizes its reliability and versatility in different social networks.

Tapaopong et al. [16] used natural language processing techniques with focus on the transformer model to improve cyberbullying detection in social media messages. Five popular models were applied: BERT, RoBERTa, ALBERT, DistilBERT, and ConvBERT. The results showed that the DistilBERT model outperformed the others, achieving accuracy 94.36%, precision 93.83%, and recall 93.91%.

Akar [17] consider the application of natural language processing techniques to detect cyberbullying in the social media environment, particularly in tweets. The results showed that the random forest and XGBoost classifiers achieve the highest Accuracy rates – 93.34% and 93.32%, respectively.

Various machine learning and deep learning models were evaluated for cyberbullying detection in study [18]. The experimental results showed that the XLM-RoBERTa model was the most effective, achieving a significant F1 Score of 0.83 and Accuracy of 82.61%, outperforming all other models.

Paul et al. [19] examines the potential of large language models (LLMs) to detect bullying in schools, in particular to distinguish between bullying and jokes in the behavior of peers. Three models were evaluated: ChatGPT-4, Gemini 1.5 Pro and Claude 3 Opus. The results showed that not all models are suitable for this approach, but ChatGPT-4 was the most effective, especially when using an agent-based approach. The study highlights the importance of using AI in educational institutions to provide real-time support, which can help reduce the negative consequences of bullying and improve the mental health of students.

For the most part, existing research is focused on finding mobbing and cyberbullying for English, but for languages such as Ukrainian, such research is poorly represented, since there are no Ukrainian-language labeled datasets.

Krak et al. [20] conducted the study that showed that detecting offensive expressions in Ukrainian-language texts is a difficult task due to the specifics of the Ukrainian language. Authors emphasized the importance of conducting such studies for Ukrainian language, therefore, an approach based on detecting offensive expressions using a dictionary and using machine learning was proposed. For this purpose, authors also created their own training dataset. As the result, using RNN neural network model, high accuracy rate of 0.96 was obtained.

Despite significant progress in the application of NLP and machine learning algorithms to detect cyberbullying, the problem of mobbing in educational environments remains insufficiently researched due to unresolved issues number. The main challenges are the lack of large volumes of high-quality labeled data specific to educational contexts, which limits the effectiveness and accuracy of model training, especially in the context of Ukrainian-language content. Furthermore, the multifactorial nature of mobbing, which includes combination of emotional,

social and cultural aspects, makes it difficult to formulate universal criteria for automatic analysis. The difficulty also lies in identifying subtle forms of mobbing, such as passive-aggressive behavior or manipulative communication, which are often difficult to detect using standard models. This study will aim to overcome such challenges.

3. Method for multifactorial analysis of mobbing behavioral signs

Mobbing, which manifests itself in posts in online educational environments, is the form of aggressive behavior that has number of characteristics that distinguish it from other forms of psychological violence and cyberbullying [21]. The main mobbing features are shown in figure 1.

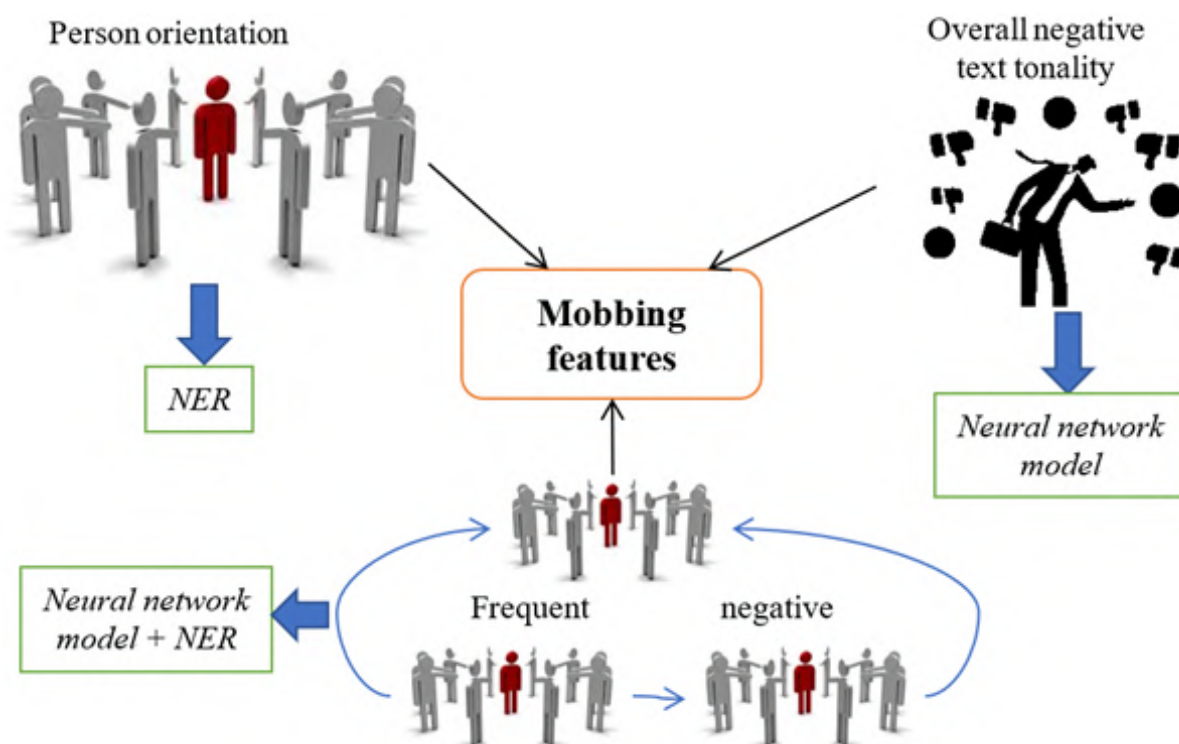


Figure 1. Approach to mobbing detection.

One of the main mobbing features is targeting a specific person, that is, attacks and assaults are directed at an individual who becomes a constant target for the aggressor. Such manifestations of aggression are not random or one-time, but are purposeful, where the victim is constantly subjected to bullying or humiliation [22]. According to existing NLP tools, targeting a specific person is formalized by searching for named entities.

The second important characteristic is the mobbing repetition, that is, its constant and repetitive nature. Internet mobbing is not limited to one message or incident, but continues for a certain time, which allows the aggressor to gradually increase psychological pressure on the victim, creating an atmosphere of constant fear or anxiety [23]. It is expressed by frequent negative references in the text to the victim of mobbing. It is implemented by searching and grouping NER and searching for tonality in relation to mentions.

Another important feature of internet mobbing is negative emotional text coloring the used by the aggressor. Messages in such cases usually contain offensive or aggressive statements, often with humiliating or derogatory elements. Such texts are aimed at causing psychological harm, lowering the victim's self-esteem and causing them to feel shame, disappointment or fear [24].

Mobbing, as phenomenon, can be mathematically represented through the set of features that characterize it. Formally, mobbing is defined as the set of features that reflects the presence of bullying behavioral elements in the text; respectively, mathematically the mobbing model can be represented as union described by the set (1):

$$M = \{w_1 \cdot F_s, w_2 \cdot F_f, w_3 \cdot F_i, w_4 \cdot G_s\}, \quad (1)$$

where F_s is the aggregate sentiment towards a specific person; F_f is the total frequency of person mentions in the text; F_i is the intensity of negative mentions towards a specific person; G_s is the overall sentiment of the text; w_1, w_2, w_3, w_4 are weighting factors, where $\sum_{i=1}^k w_i = 1$.

The aggregate sentiment towards a specific person (F_s) is determined by (2):

$$F_s = \frac{1}{N} \sum_{i=1}^N P_i, \quad (2)$$

where P_i is the sentiment score for the i -th mention of person under study; N is the mentions total number.

The total frequency of person mentions in the text (F_f) is determined by (3):

$$F_f = \frac{N_p}{N_{all}}, \quad (3)$$

where N_p is the mentions number of person under study; N_{all} is the total mentions number of persons in the text under study.

The intensity of negative mentions towards a specific person (F_i) is given by (4):

$$F_i = \frac{N_n}{N_{all}}, \quad (4)$$

where N_n is the negative mentions number of person under study; N_{all} is the total number of mentions of a person in the text under study.

The assessment of the manifestation of mobbing (IM) in relation to a person under study in the text is calculated by (5):

$$IM = w_1 \cdot F_s + w_2 \cdot F_f + w_3 \cdot F_i + w_4 \cdot G_s, \quad (5)$$

where F_s is the aggregate sentiment towards a specific person; F_f is the total mentions frequency of a person in the text; F_i is the intensity of negative mentions towards a specific person; G_s is the overall sentiment of the text; w_1, w_2, w_3, w_4 are weighting factors, where $\sum_{i=1}^k w_i = 1$.

The overall intensity of mobbing in the text is calculated as aggregated intensity estimate for all persons mentioned in the text (6):

$$IM_{total} = \frac{1}{N} \sum_{i=1}^N IM_i, \quad (6)$$

where IM_{total} is the total mobbing intensity in the text; N is the number of persons mentioned in the text message; IM_i is the value of mobbing intensity in the text calculated by (5).

Taking into account the above-mentioned signs of mobbing, the method for multifactorial analysis of mobbing behavioral signs in educational environments posts by NLP means processing

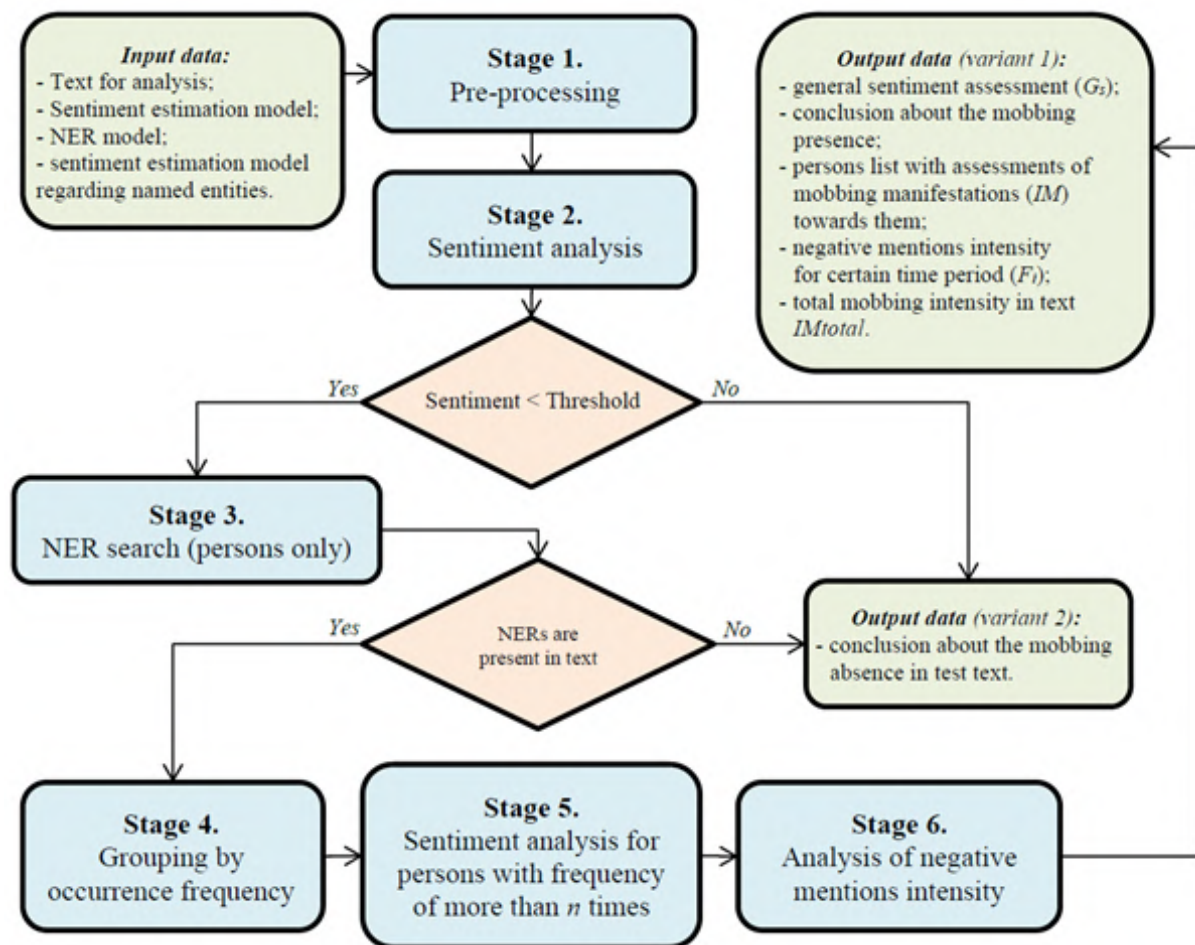


Figure 2. Method for multifactorial analysis of mobbing behavioral signs in educational environments posts by NLP means.

tools is proposed. Method is based on the identification of above-mentioned signs, which will allow detecting mobbing in text messages by analyzing their content from view point of described signs. The scheme of method is shown in figure 2.

The method for multifactorial analysis of mobbing behavioral signs in educational environments posts by NLP means involves 6 stages. The input data for method are text posts for analysis that may potentially contain mobbing signs. In this case, this is a text containing posts from a private chat of educational environment, collected over a certain period of time, but anonymized, that is, they do not have a label regarding author of post, and names in the text are replaced with arbitrary ones. In the analysis process, model is used to determine the overall sentiment score G_s of input text, which allows identifying the overall level of sentiment in the range from 0 to 1, where 0 is the most negative sentiment, and 1 is the most positive sentiment. Additionally, model is used to detect NER, which allows finding mentions of specific individuals in text who may be targeted by mobbing. The last component of input data is neural network model that analyzes sentiment regarding identified named entities, which allows investigating emotional attitudes towards specific individuals mentioned in text.

The scheme of converting input data into output data is shown in figure 3.

At stage 1, text data is pre-processed, which includes cleaning the text from unnecessary elements, such as special characters and stop words. At this stage, it is inappropriate to remove

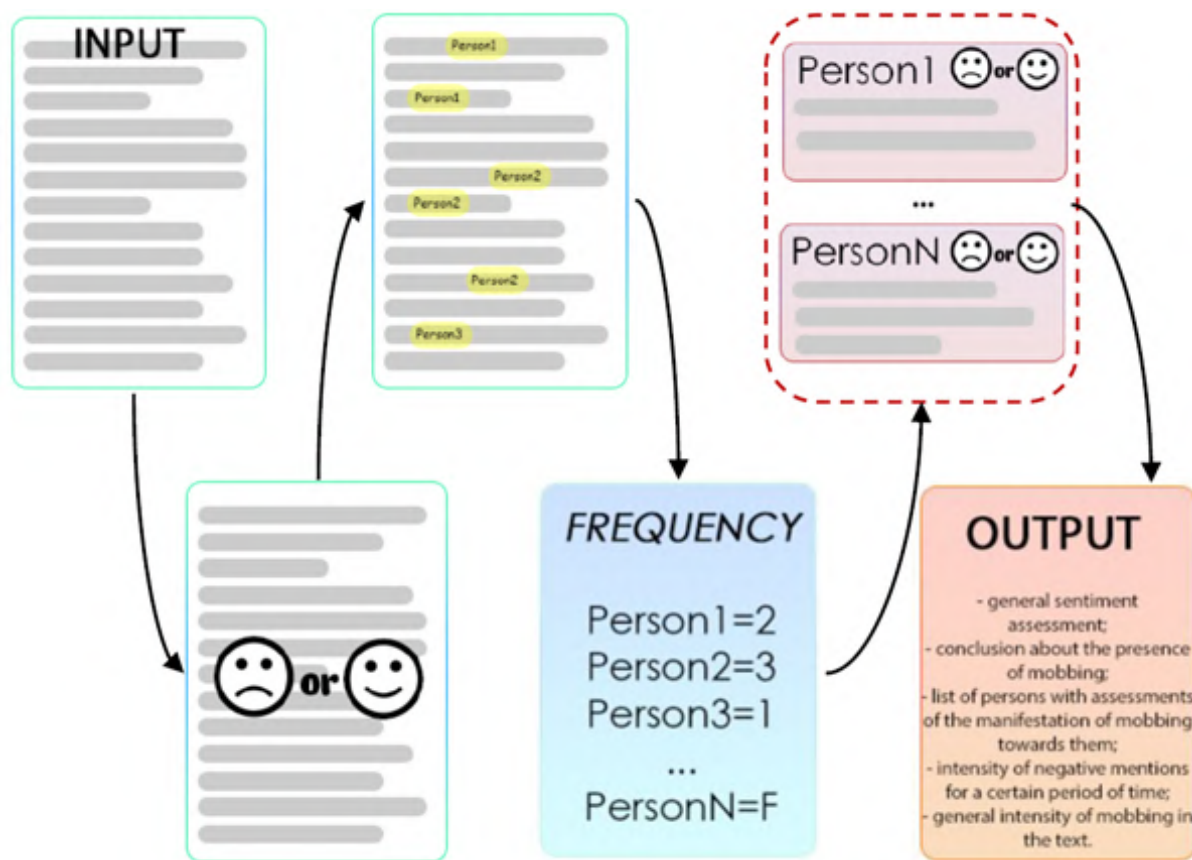


Figure 3. Converting data using the method for multifactorial analysis of mobbing behavioral signs.

punctuation marks, such as periods, commas, question marks and exclamation marks, since they can carry important semantic information that affects the accuracy of further analysis, both of the sentiment of the text message and of the definition of named entities. After this, text tokenization is performed, which simplifies further data processing.

At stage 2, general analysis of text sentiment G_s is performed, which is measured as numerical value that is compared with defined threshold from 0 to 1. The threshold is determined empirically, which allows for more accurate classification depending on text volume for analysis and subject area. If positive sentiment level of exceeds the set threshold, conclusion is made that there is no mobbing in the post, and method ends at this stage, since mobbing is aimed at harassment and humiliation, which has negative focus as marker.

Stage 3 occurs if sentiment level of the text G_s is lower than the threshold value. At this stage, search for named entities is carried out, limited exclusively to category of persons. In this case, pronouns that may be present in the text and may also indicate a person and semantic terms related to the person [25] who is targeted by mobbing are not taken into account. This approach is explained by the fact that pronouns, usually, do not contain sufficient information to clearly identify specific persons and can only indirectly indicate them, and are also limitations of the proposed method. The inclusion of only named entities that clearly mention specific persons allows ensuring that mobbing is directed at a specific person. If named entities are not detected in the analyzed text, a conclusion is made about the absence of mobbing in it.

At stage 4, if the text contains named entities, they are grouped by mention frequency

F_f , which allows to identify those persons who are mentioned more than a certain number of times. Grouping named entities also makes it possible to establish relationships between different persons, which may indicate the presence of patterns or regularities in the interaction of persons in texts. Persons are grouped by lemmatization (reduction to a single word form).

At stage 5, which based on the grouping of persons by frequency of mention F_f , an in-depth sentiment analysis is performed for each of the selected persons P_i . The threshold frequency of mentions is also determined empirically and depends on the number of named persons found in the text and the total length of text. The purpose of this stage is to determine the nature of emotional attitude towards specific persons, which may indicate the presence of signs of mobbing against specific persons. After all, several named entities may be present in the text, to which different sentiments, both positive and negative, can be attributed, even if the overall text sentiment is determined as negative at stage 2.

Last stage 6 is the analysis of negative mentions intensity F_i in text. At this stage, number and frequency of negative statements over a certain period of time are determined, which allows assessing the overall intensity of mobbing manifestations.

Output data of method includes the overall sentiment assessment of text G_s , the conclusion about presence or absence of mobbing, the list of persons with corresponding assessments of mobbing manifestation IM regarding them, the overall intensity of negative mentions in text F_i and the overall mobbing intensity in text IM_{total} .

So, method for multifactorial analysis of mobbing behavioral signs in educational environments posts is proposed, which takes into account key mobbing features: directionality, repetition, mentions frequency, negative attitude intensity and general tone of text. Method provides mobbing detection by analyzing text data using NER, sentiment analysis and assessment of negative impact on specific persons, which allows identifying psychological pressure intensity and assessing mobbing scale.

4. Experiment

The study conducted comparative analysis of 50 Ukrainian-language texts marked by 4 experts (34 texts had negative tone, and 16 had positive tone) with length of studied fragments from 200 to 400 words according to following parameters (table 1). In all fragments of studied group, names were not repeated and number of persons discussed ranged from 0 to 10.

The data obtained by experts were compared with implementation of proposed method for multifactorial analysis of mobbing behavioral signs in educational environments posts in website form (figure 4). The Python programming language and the Flask framework were used to develop software. Also, to implement the proposed method, “torch” and “transformers” libraries were used to determine text general sentiment, and for sentiment regarding found named entities, “stanza” library was used to search for named entities.

The figure 4 shows software application designed to analyze behavioral signs of mobbing in text messages, particularly in educational environment. The main application function is to detect mobbing signs, such as negative sentiment of text, targeting specific person, and repetition.

The results are presented in the form of numerical indicators that simplify interpretation. Additionally, the application displays specific messages where signs of mobbing are recorded for a specific named entity, which provides an additional visual interpretation of results obtained. The output of not only general assessment of mobbing, but also personalized assessments of presence of mobbing and factors that influenced the decision contribute to results explainability and increase confidence in decisions made by artificial intelligence.

Table 1. Text evaluation parameters for mobbing detection.

Parameters	Scale and method of assessment
General sentiment of the text	Binary assessment (positive/negative)
General sentiment of the text	Numerical assessment from 0 to 1 (0 – minimum negative score, 1 – maximum positive score)
Number of people mentioned in the text fragment	Numerical assessment
Mentions number for each of listed persons	Names & numerical estimates of mentions frequency
Averaged sentiment towards each of the mentioned persons	Names & average sentiment for each person
Frequency of negative mentions for each person	Names & negative mentions frequency
List of persons to whom mobbing was applied and assessment of mobbing manifestation in relation to persons	Names & intensity from 0 to 1 (0 – no mobbing, 1 – maximum mobbing)
Overall assessment of mobbing level in text	Numerical assessment of mobbing overall level in text (0 is absent, 1 is maximum mobbing presence)

5. Results and discussion

To analyze the sentiment for each of selected persons, at stage 5 of proposed method, the mBERT model is used, which allows determining the sentiment of statements regarding named entities, which are determined using Stanza [26] at stage 3 and selected at stage 4 as the most mentioned in the text for analysis. The choice of mBERT to determine the sentiment for each of selected persons is justified by its ability to work with multilingual texts, in particular Ukrainian. The mBERT model is able to determine the sentiment for each of selected persons due to its ability to perform deep contextual analysis. Thanks to its transformative architecture, it takes into account the relationships between words and their context, which allows estimating tone, even without additional training on specific tone determination tasks [27, 28].

This study is continuation of previous researches [20, 29], to find Gs, the previously trained and tested in previous researches RoBERTa model, retrained on Ukrainian texts, will be used. In the previous research [30] it was shown that this model achieves high Accuracy and Loss for different numbers of epochs and batch sizes, which is shown in table 2.

Table 2. Classifier RoBERTa retraining parameters.

Training epochs number	Batch size	Accuracy	Loss
3	64	0.92	0.29
3	32	0.91	0.31
4	32	0.91	0.31
5	32	0.91	0.32
3	16	0.91	0.31
10	64	0.92	0.30

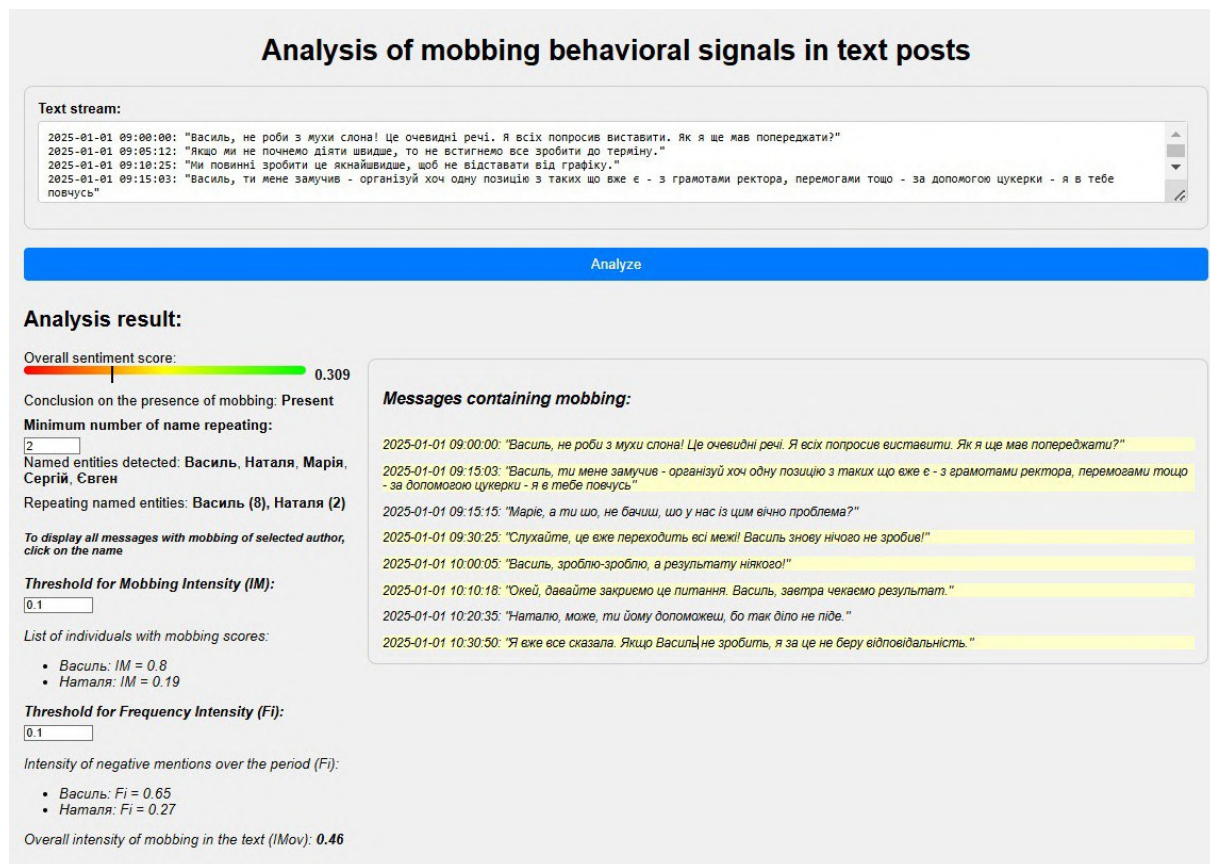


Figure 4. Experimental software for multifactorial analysis of mobbing behavioral signs.

Developed software analyzes the text, first determining the general sentiment. As can be seen from figure 4, a negative sentiment with score of 0.309 is determined for analyzed text. Next, search is carried out for named entities in the text, namely persons. In analyzed text, 5 persons were found and the evaluation of manifestation of mobbing (IM) was calculated for two of them, since other persons were not mentioned in negative context, the negative mentions intensity for certain period of time (F_i), the overall mobbing intensity in text IM_{total} and conclusion was formed about mobbing presence.

The table 3 shows performance comparison of proposed method for multifactorial analysis of mobbing behavioral signs in educational environments posts by NLP means with the implemented software and the averaged results obtained by experts.

The analysis of obtained data demonstrates the effectiveness of developed software based on proposed approach in determining the key parameters of mobbing; however, some discrepancies between the expert assessments and the software are still present. The overall average correlation between the expert assessments and the software exceeds 90% for most parameters, which indicates the possibility of automated mobbing detection in Ukrainian-language texts. In particular, in determining the number of negative texts by binary assessment, the software showed full correctness (100%) with slight deviation in the average value (34 versus 33.25 for experts). In one of the 50 texts, the experts could not reach a common opinion, and 1 of them indicated a different assessment of the tone from the opinion of others experts. The correlation for this parameter is 97.79%, which was affected by the ambiguity in the experts' opinions.

The assessment of text overall sentiment (numerical scale from 0 to 1) also demonstrates

Table 3. Performance comparison of proposed method and averaged results obtained by experts.

Parameters	Average value obtained by experts	Average value obtained by developed software	Correct identification by developed software, %	Correlation between software and expert, %
Number of negative texts by binary score	33.25	34	100	97.79
Overall text sentiment (numerical score from 0 to 1)	0.334	0.31	–	92.81
Number of persons mentioned in text fragment	4.6	4.5	98	97.83
Number of mentions for each of listed persons	2.1	2.05	97.6	97.62
Averaged sentiment towards each of mentioned persons	0.489	0.453	–	92.64
Frequency of negative mentions for each person	1.3	1.3	100	100
The number of persons to whom mobbing was applied	3.2	3.3	99	96.97
Assessment of mobbing use with manifestation severity from 0 to 1 per person	0.15	0.17	–	88.24
Overall assessment of the mobbing level in the text	0.28	0.289	–	96.89
The number of texts that contain mobbing	26.75	27	100	99.07

significant agreement at 92.81%, which confirms the previous studies results using this neural network. It is also worth noting that the difference may be due to nuances of assessment, such as the sensitivity of software to text contextual features. To increase the percentage of correlation, it is necessary to further train the neural network on texts found in the educational environment.

In determining the number of persons mentioned in the text fragments, the software showed high accuracy (98%) and almost identical average values (4.6 for experts and 4.5 for the program). However, the differences in this parameter arise because the software does not take into account pronouns that experts can use to identify persons. This limitation may partially affect the accuracy of automatic assessment, and its study will become the basis for further research.

The frequency of mentions for each person was also detected by software with high accuracy (97.6%), with mean value of 2.05 versus 2.1 for experts. The correlation for this parameter is 97.62%, confirming software ability to reproduce the experts' assessments in this aspect. Software demonstrated similar accuracy in determining negative mentions frequency, where correlation is 100% and the mean values completely coincide.

Regarding the mobbing parameter, software identified persons who had been mobbing with 99% accuracy. The slight difference in mean values (3.3 in software versus 3.2 in experts) and correlation at 96.97% are also related to pronouns that are taken into account by experts but not by software. The assessment of mobbing manifestation strength (from 0 to 1) showed lower correlation (88.24%), which is probably due to subjectivity of expert assessment and lower sensitivity of algorithm to weak mobbing manifestations.

The overall assessment of mobbing level in text and number of texts containing mobbing demonstrate a very high correspondence between expert assessments and automatic analysis. The correlations for these parameters are 96.89% and 99.07% respectively, and mean values practically coincide.

Therefore, results indicate that developed software is a highly effective tool for analyzing texts at the level of sentiment parameters, mentions of persons, and mobbing level. Minor discrepancies, in particular in number of persons and assessment of mobbing, are associated with algorithm limitations, which does not take into account pronouns or other contextual features that experts took into account.

6. Conclusions

Method for multifactorial analysis of mobbing behavioral signs in educational environments posts by NLP means has been developed, which allows not only to detect the such signs presence of mobbing behavioral, but also to analyze their intensity and direction, providing systematic analysis of behavioral trends in texts. The developed method differs from existing ones by multifactorial detection of mobbing in educational environments based on a set of factors that are separately determined; using threshold values and coefficients of influence of each factor on the final result. The method has universal structure, which allows it to be adapted to various areas of application by modifying threshold values for assessing behavioral signs. This ensures its suitability for automatic mobbing detection in various contexts, in particular, educational environments, social networks, corporate environments, professional communities etc.

The mathematical model of mobbing uses set of factors, such as aggregate sentiment towards person, mentions frequency, intensity of negative mentions and general sentiment. This allows for an objective assessment of mobbing manifestations in texts, on basis of which it is possible to determine the level of psychological violence in teams.

Method for multifactorial analysis of mobbing behavioral signs in educational environments posts by NLP means consists of number of stages, including text preprocessing, sentiment analysis, named entities recognition and grouping entities by mentions frequency. As the result, emotional attitude towards separate individuals and intensity of corresponding negative mentions are assessed, which allows to distinguish and evaluate mobbing. This approach has important practical significance for automated detection and assessment of aggressive behavior in online environments.

The results obtained by developed method show average of correlation with expert opinions at 95.99%, which shows possibility of automating the detecting mobbing process in educational environments.

Proposed approach has the number of limitations, including size of input text data stream from 200 to 400 words (limitation is imposed by neural network to search for general sentiment based on training data), the lack of associations for pronouns, and is applied to relatively small communication groups (all persons must have unique names), so further research will be aimed at eliminating these limitations. Future research directions in this area include cross-linguistic applications, dataset scaling, and real-time deployment.

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Virtual laboratory work with augmented reality elements to teach metal hardness measurement

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Abstract. The article presents the development and implementation of a custom application with augmented reality elements for teaching metal hardness measurement during laboratory work in the disciplines “Materials Science and Technologies of Structural Materials” and “Electrical Engineering Materials”. During air raid alerts and missile threats, the learning process is carried out in shelters that are not equipped with laboratory devices. To facilitate teaching students how to measure metal hardness during remote learning, a specialized application was developed. The study includes four stages: a theoretical review of literature; the creation of electronic models of metal hardness testing equipment in a CAD system; the development of an application with augmented reality features in the Unity game engine; an analysis of student performance outcomes after studying the topic with the use of the application. The stage of using the proposed application involves students completing tasks and earning points. For statistical verification of the application of the developed tool in the learning process, the Pearson criterion was used. The pedagogical experiment demonstrated that students in the experimental group achieved a quality success rate 14 percentage points higher than that of the control group. This indicates the effectiveness of the application implemented in the educational process.

1. Introduction

In modern conditions, one of the key tasks of the educational process is the implementation of educational programs using distance learning technologies [1–3]. The development and implementation of distance learning tools has become especially important during the COVID-19 pandemic [4–6]. For the second time, the necessity for distance educational technologies in Ukraine arose during the full-scale Russian aggression [7, 8]. During air raid alerts and missile threats, the educational process continues in shelters, which are typically not equipped with laboratory instruments. Some educational institutions have made the decision to transition to a distance learning format. This has again increased the demand for distance learning technologies. Significant attention from educators has been drawn to methods and approaches for conducting laboratory work in a virtual format using browser-based programs or standalone AR/VR/XR applications [9, 10]. Today, a substantial number of teaching methodologies for humanities and natural sciences in a distance format have been developed, reflected in various studies, and implemented in scientific publications [11, 12]. Most often, this topic is examined



from a theoretical perspective or includes practical examples, such as the exchange of electronic resources through distance learning systems like Moodle [13].

Typically, laboratory experiments during distance learning are suggested to be conducted in the following ways [14]:

- in the form of video recordings of real experiments and their repeated demonstration to students;
- conducting virtual experiments;
- conducting experiments using specialized software-hardware systems with remote access in real-time, including the measurement of parameters and subsequent discussion of the results.

The most challenging method to translate into a distance learning format is the last one listed above — laboratory work. Undoubtedly, laboratory work is designed to teach students how to conduct experiments and master the skills of working with real instruments and laboratory setups. In turn, virtual labs serve as a complement to laboratory work conducted on the technical basis of a real educational laboratory [15–18]. However, as recent events related to the pandemic and the ongoing conflict in Ukraine have shown, virtual laboratory work may temporarily become the primary form of conducting laboratory sessions. Therefore, this research is directly related to the possibility of transferring laboratory practice to a distance format, if necessary, and is thus highly relevant.

One of the problems with virtual labs is their development or access to similar electronic resources. The simplest method is to use pre-existing programs that have been developed by specialized companies [19]. It is also possible to find virtual laboratory programs that have been made publicly available by their authors [20]. A more complex approach is the development of custom educational computer programs [21, 22]. Typically, the development of educational electronic resources requires the involvement of relevant specialists, such as project managers, programmers, UX/UI designers, testers, and others.

2. Theoretical analysis of the research problem

Recent developments in virtual laboratory work effectively model real experiments and realistically depict laboratory setups. Just as in actual laboratory work, students take measurements, manipulate the components of the setup, and interact with measuring instruments. Some virtual models also generate graphs simultaneously while recording experimental data [23].

The main disadvantage of performing virtual laboratory work is the lack of direct contact between the student and the instruments and equipment [24]. However, this method still allows students to practice all the skills that these sessions aim to develop. The student learns to apply acquired theoretical knowledge in practice, predict expected results based on theoretical principles, use measuring instruments, and process experimental data obtained with their help.

Given the freedom provided to the instructor in choosing tasks for the work, virtual practices can be divided into two types. In the first case, one or two given dependencies are recorded, after which a graph is often immediately constructed. Alternatively, based on the given initial conditions, a specific parameter of the studied system is determined [25]. In most cases, developers of such laboratory works accompany their tasks with descriptions outlining specific tasks [26]. The instructor is left with the only task of following the provided instructions.

The second type of work involves manually setting several initial parameters, which allows the instructor to choose which dependencies students should explore, which graphs to build, and which parameters to calculate. These virtual tasks can effectively replace real laboratory work done at the educational institution [27]. Each task comes with detailed instructions. They are

similar to real laboratory exercises done during in-person classes. All tasks are independent and can be done without an internet connection.

The difficulty of performing such tasks arises from the fact that no detailed step-by-step instructions are provided. The student is given almost complete freedom of action. They must figure out what can be measured and then create a step-by-step plan, as sometimes the order of actions is important to obtain the correct result. Such tasks are great for developing the thinking of an experimenter. They can be assigned as a separate lab exercise or as an individual task for students who easily handle the basic tasks of the lab work.

Virtual laboratories provide the necessary flexibility to organize the educational process in a remote format [28]. A laboratory workshop can be organized in the traditional way [29]:

- at the beginning of the session, students are granted access to the work through video communication tools (Google Meet, Zoom, etc.);
- then, the instructor provides them with a link to the laboratory work;
- students complete the work in a limited period of time, the same as the time allocated for completing the work in a full-time study format;
- at the end of the session, they either show or send the report to the instructor, or defend it immediately, depending on the established procedure for in-person learning.

An alternative option is to give students the opportunity to do their work at their own convenience. The task is posted on the platform used for distance learning at the educational institution. The steps for completing the work are as follows:

- obtaining admission to work in the form of a test assignment. After successful completion of the task, a link to the virtual laboratory work and a file with methodological recommendations are automatically provided;
- completing the work;
- preparing the report;
- defending the work (later in a separate online session or through completing an individual task).

This mode does not require the presence of a teacher during the admission process. The student can do the work not only during scheduled classes [30].

When developing a program for the case of a forced transition to distance learning, it makes sense to select virtual laboratory works similar to those performed in person [31]. In this case, the laboratory practice can continue during the temporary transition of the student group to a distance learning format after the semester begins and then return to in-person learning before the semester ends. If necessary, the virtual laboratory practice can be more extensive than in-person work. For example, it can include laboratory tasks that, in a physical setting, require special conditions (such as field laboratory work at companies) [32, 33].

Another advantage of using a virtual workshop is the ability to organize frontal laboratory work, which is not always possible during face-to-face training due to the very limited number of identical laboratory facilities [34]. Conducting laboratory work frontally allows all students to be placed in the same conditions, avoiding situations where some students work on topics already covered in lectures and practical sessions, while others work ahead and tackle topics that will be studied later in the same semester.

Considering the current development of information technology, a virtual laboratory practice can effectively replace in-person laboratory sessions [35]. Educational institutions may consider this form of conducting laboratory work in case of the need to transition to a distance learning format [36, 37].

The aim of this study is to present the author's development and implementation of an application with elements of augmented reality for teaching the measurement of metal hardness during laboratory work in the course "Materials Science and Structural Materials Technology" for students of the specialties 208 "Agroengineering", 133 "Industrial Engineering" and 274 "Automobile Transport", as well as the course "Electrotechnical Materials" for students of the specialty 141 "Power Engineering, Electrical Engineering, and Electromechanics".

3. Description of the program's functionality

During the preparation of future engineers, acquiring practical skills in using measuring instruments [38], including those for measuring hardness, plays a crucial role. These skills are developed by students during the laboratory work on the topic "Determination of Metal Hardness" in the educational courses "Materials Science and Technology of Structural Materials" and "Electrotechnical Materials". The skills are acquired through the use of hardness testers in real-world conditions in direct contact with the tool.

Hardness is defined as the property of a metal to resist the penetration of a harder material, an indenter. The indenter does not undergo permanent deformation during the test [39]. Typically, the hardness of a metal is determined by the following methods: Brinell (GOST 9012-59), Rockwell (GOST 9013-59), and Vickers (GOST 9450-76). In this work, all developments are demonstrated using the example of hardness determination by the Brinell method (figure 1a).

When determining hardness using the Brinell method, a metal ball is pressed into the test specimen. After the load P is removed, a spherical indentation remains on the surface of the specimen. The size of the indentation depends on the hardness of the metal – the harder the



(a)



(b)

Figure 1. Laboratory equipment for determining hardness by the Brinell method, (a) – HS-2M hardness testing device; (b) – microscope with measuring scale.

metal, the smaller the indentation. To determine the hardness number (HB), the applied load P must be divided by the spherical surface area of the indentation F . Balls made of hardened steel or hard alloy with diameters of 2.5, 5.0, and 10 mm are used for testing. The load applied to the indenter varies from 156 to 30,000 N, depending on the metal's hardness. To ensure that the test results are comparable regardless of the diameter of the ball used, the relationship between the applied load and the ball diameter must be maintained as: $P = 25D^2$ and $P = 300D^2$.

During distance learning or air alerts, students are not able to conduct real experiments, so these tasks cannot be fully considered as laboratory work. Although students can observe real experiments through video recordings and analyze the data, they do not directly participate in the experiment. While watching the videos, students essentially see a demonstration of the experiment, which usually only shows successful results. In real demonstrations, the instructor can repeat the experiment and explain any failures. However, this is only possible in online experiments. Therefore, there is a need to develop an application with augmented reality elements, allowing students to explore the structure and basic operation of laboratory equipment for hardness testing in conditions close to the real ones.

The research was carried out in the following sequence:

- a theoretical review of literature sources on learning through virtual laboratory work using augmented and virtual reality during distance and independent learning was conducted;
- electronic models of equipment for determining the hardness of metals were developed in a CAD system;
- an educational application with augmented reality elements was developed in the Unity game engine;
- the results of students' performance after studying the topic using the educational application were analyzed.

The application was developed on a personal computer with Windows 10 (64-bit version). This application contains marker-based augmented reality elements. The markers were developed using the Vuforia augmented reality platform. A new database was created in the Target Manager account, and target images were uploaded. Figure 2 shows an example of a target image for the Brinell method. The target images are processed by Vuforia's computer vision tools and receive rating scores from 1 to 5 stars. The best images have 5 stars. They are recognized quickly and accurately by the application. The minimum recommended rating is 3 stars. The database of target images is downloaded from the Vuforia website and installed in Unity.

The object of the study is the informational and educational application "Metal Hardness Measurement" for conducting the corresponding laboratory work in the disciplines "Materials Science and Technology of Structural Materials" and "Electrical Engineering Materials" during distance and self-directed learning for students of technical specialties. The hardness of metals is determined using laboratory equipment. Therefore, the main element of the program is the electronic model of the hardness tester. Various 3D modeling programs, such as Blender or 3Ds Max, can be used to create the electronic model [40]. Figure 3 shows the electronic model of the hardness tester, developed in a CAD system.

The electronic model (assembly) consists of the following components (parts): 1 – body; 2 – handwheel; 3 – screw; 4 – specimen table; 5 – tested metal; 6 – ball; 7 – lever system; 8 – weights; 9 – time relay. Each component of the hardness tester has been developed as a separate element. The parts have been combined into an assembly and saved in the obj format.

The mobile application was developed as a methodological and practical educational information program. It contains information on the theoretical background for working with

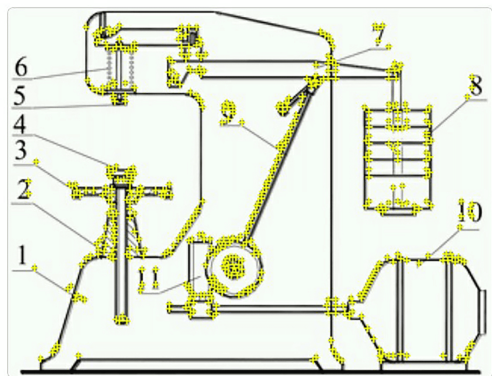


Figure 2. An example of a target image in Vuforia.

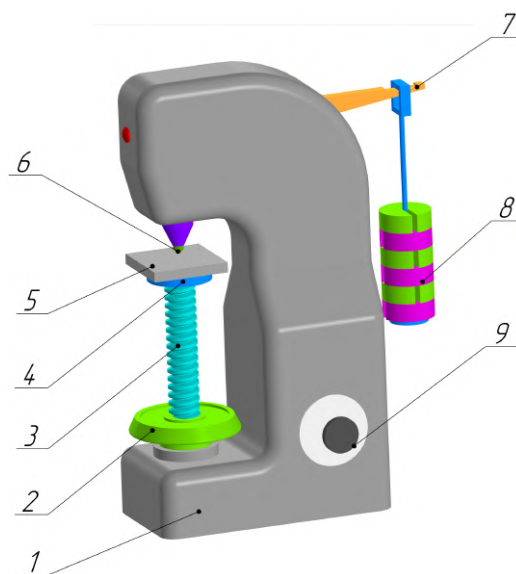


Figure 3. Electronic model of hardness tester HS-2M.

hardness testers and a practical simulator for operation. The main screen of the application (figure 4) displays three buttons for learning hardness determination methods: Brinell, Rockwell, and Vickers.

After pressing the “Brinell Method” button, the user is directed to a window (figure 5) for configuring the parameters to determine hardness using the Brinell method. The smartphone’s camera activates to search for and track the target image. When the camera is aimed at the target image, the corresponding hardness tester model is displayed on the screen. At the bottom of the screen, there are buttons to select the experiment parameters: indenter (ball) diameter, load, and the dwell time of the indenter in the test sample. The selected parameters are highlighted in green.

At the top of the screen, there is a button to return to the main screen of the application and a “START” button. The “START” button initiates an animation of the indenter pressing into the test sample. The animation includes the vertical movement of the indenter and audio content that simulates the operation of the equipment.

The next step in determining the hardness of the metal using the Brinell method is measuring the diameter of the indenter (ball) impression on the surface of the test sample. The diameter of the indenter impression is measured using a microscope with a measuring scale (figure 1b).

Figure 6a shows a photograph of the indenter impression. To increase the variety of tasks, each time the application is launched, the photograph of the indenter impression is randomly scaled between 0.95 and 1.05. This ensures that each student receives an individual version of the task. A measuring scale image is superimposed over the photograph of the indenter impression. It has a transparent background, so only the measuring scale is visible. The movement and rotation of the measuring scale are controlled via the phone’s touchscreen.

The diameter of the indenter impression is measured in two mutually opposite directions. The average value of the indenter’s impression diameter is used to determine the hardness of the metal using the tables (figure 6b). At the bottom of the application’s screen, a search bar is included. If the diameter of the indenter impression is entered into the search bar, the program will automatically highlight the corresponding hardness value in the table with a green color.

During the laboratory work using the app, students are required to take screenshots of the



Figure 4. Program head screen.



Figure 5. Parameter setting window.

phone screen at each stage of the measurement. The saved images are added to the report and sent to the instructor's email for verification.

4. Implementation of the application in the educational process

To confirm the effectiveness of the conducted study, it is necessary to formulate a null hypothesis and test it. A statistical hypothesis is an assumption about the characteristics of a general population that can be tested based on the results of a sample observation. The essence of hypothesis testing lies in determining whether the sample results are consistent with the hypothesis, and whether the differences between the hypothesis and the sample data are random or non-random.

Solving any statistical hypothesis testing problem always begins with defining the null and alternative hypotheses. The main hypothesis is referred to as the null hypothesis and is denoted as H_0 . Alongside the null hypothesis H_0 , an alternative hypothesis H_1 is always considered, which competes with the null hypothesis.

The null hypothesis H_0 is tested using statistical methods, which is why the process is called statistical hypothesis testing. The rule by which a decision is made to reject or not reject the statistical hypothesis H_0 is called a statistical criterion.

Pearson's criterion provides the lowest probability of second-order error compared to other agreement criteria, which is why it was chosen in our study. The criterion is based on a comparison of theoretical and empirical frequencies.

To confirm the effectiveness of the conducted research, we propose the null hypothesis H_0 , which states that there is no effect of the developed augmented reality-based application for learning metal hardness measurement during laboratory work in the courses "Materials Science and Technology of Structural Materials" and "Electrotechnical Materials" on students' academic achievements. The alternative hypothesis H_1 suggests that the use of the developed application does influence the level of students' academic achievements in the aforementioned topic.

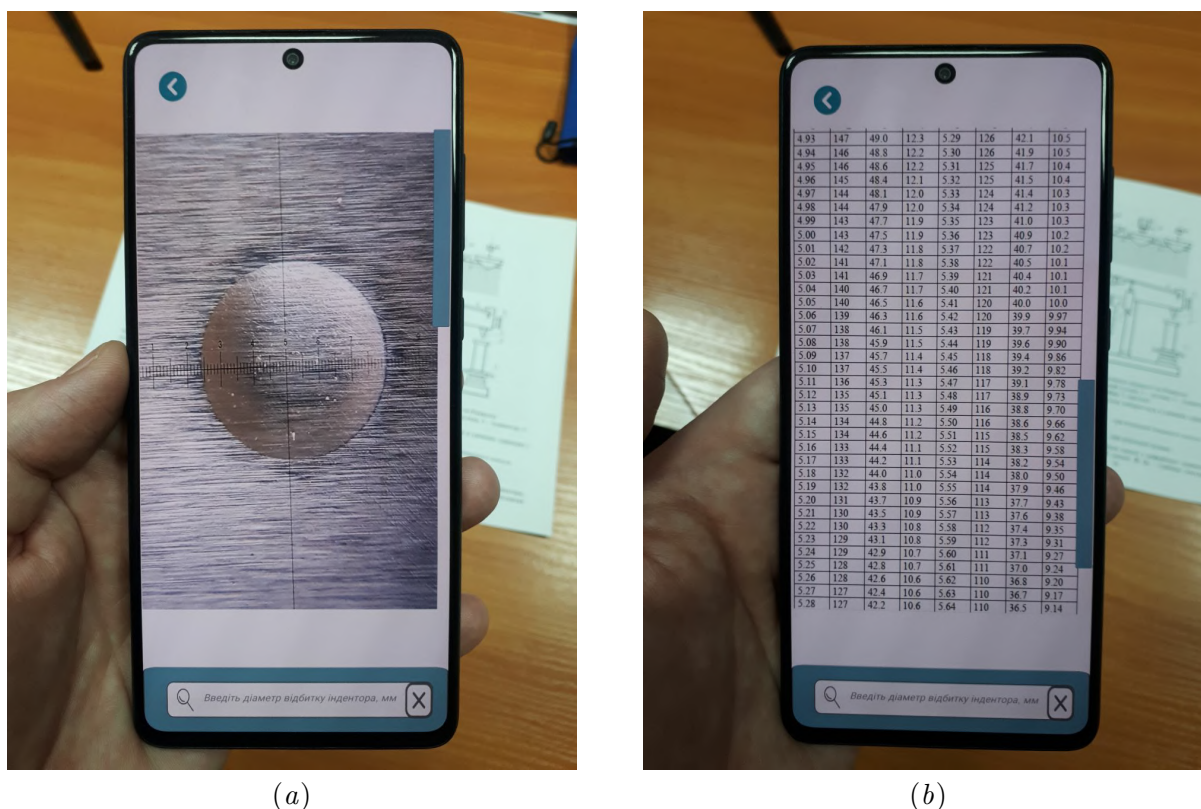


Figure 6. The process of determining hardness by the Brinell method, (a) – indenter imprint; (b) – table for determining the metal hardness index.

The experiment involved 244 students from the specialties 208 “Agroengineering”, 133 “Industrial Engineering”, 274 “Automobile Transport”, 192 “Construction and Civil Engineering”, and 141 “Electrical Engineering, Electrical Engineering, and Electromechanics” at Poltava State Agrarian University. Homogeneous study groups were selected for the experiment: experimental (EG) and control (CG) groups. The control group consisted of 123 students, and the experimental group included 121 students. Both the EG and CG students were classified according to their academic achievement levels based on a 4-point grading scale: “excellent” (A) – high, “good” (B, C) – sufficient, “satisfactory” (D, E) – average, and “unsatisfactory” (FX, F) – low.

The experiment was conducted in 2023-2024. During this period, there were significant air raid alerts, during which students had to leave the laboratories and move to safe places. In shelters, the educational process continued using distance learning technology – watching educational videos and taking notes on theoretical material. Meanwhile, the students in the experimental group (EG) also used the developed application to acquire practical skills in measuring the hardness of metals. The integrity of the experiment was ensured by a unified method of assessing students’ achievements – testing. The data, reflecting the level of students’ achievements on the specified topic, were collected after the completion of the formative stage of the experiment and are presented in table 1.

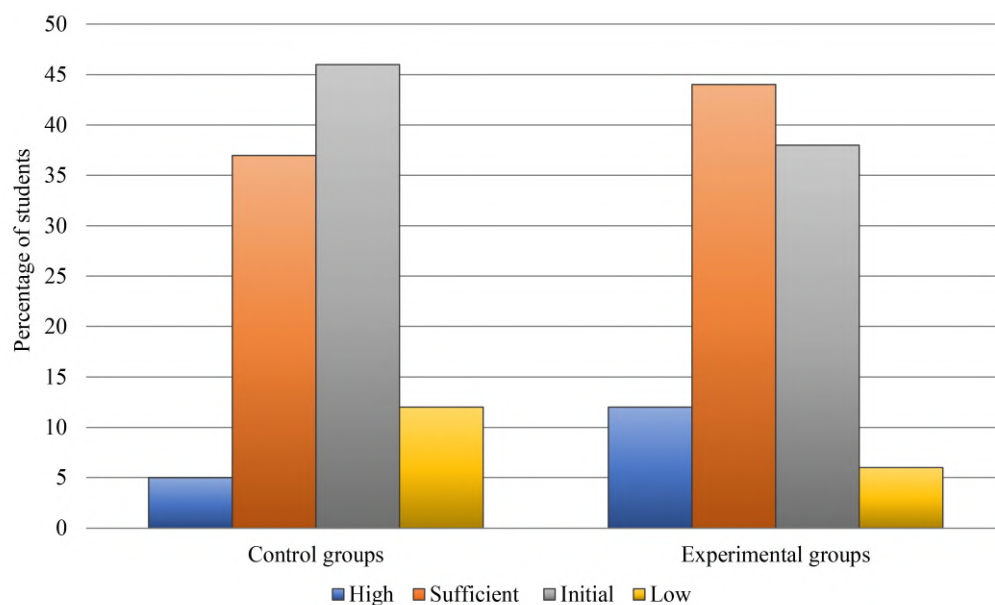
In the experimental group (EG), the number of students who achieved high and sufficient levels of academic performance increased by 7% and 7%, respectively. Moreover, the number of students with a “low” level of academic performance decreased by half. The positive trend in the average grade success rate of the experimental group students indicates a higher level of

Table 1. Comparative analysis of students' achievements on the topic "Measuring the hardness of metals".

Group	Number of students	Levels of academic achievement								Average score
		High		Sufficient		Medium		Low		
		Num.	%	Num.	%	Num.	%	Num.	%	
CG	123	6	5%	45	37%	57	46%	15	12%	3.34
EG	121	15	12%	53	44%	46	38%	7	6%	3.63

achievement development in the process of studying the topic "Measurement of Metal Hardness" with the help of the developed augmented reality-based application.

The indicators of the students' academic achievement levels at the end of studying the above-mentioned topic are displayed in the diagram (figure 7).

**Figure 7.** Diagram of students' learning achievements at the end of the pedagogical experiment.

To test the hypothesis we proposed, we conducted pairwise comparison of the academic achievement levels of students in the control and experimental groups. The results were processed using the Pearson's correlation test [41].

Find the value of the statistic χ_{emp}^2 according to the formula:

$$\chi_{emp}^2 = \sum \frac{(n_{ij} - np_{ij})^2}{np_{ij}}, \quad (1)$$

where n_{ij} – empirical frequency, np_{ij} – theoretical frequency:

$$np_{ij} = \sum \frac{(R_i \times C_j)}{N}, \quad (2)$$

where R_i – total sum for row i , C_j – total sum for column j , N – total sum of all variants.

We obtained $\chi_{emp}^2 = 8.57$.

According to statistical tables for the level of significance $\alpha = 0.05$ degrees of freedom for $k = (4 - 1) \times (2 - 1) = 3$ we find the critical value of the test statistic $\chi_{crit}^2(\alpha = 0.05; k = 3)$:

$$\chi_{crit}^2(0.05; 3) = 7.81.$$

We found that

$$\chi_{emp}^2 > \chi_{crit}^2.$$

The calculated data is presented in table 2.

Table 2. The results of the study on students' academic achievements in the topic "Measurement of Metal Hardness" after conducting the experiment are presented.

Level	EG, n_{ij}	CG, n_{ij}	EG, np_{ij}	CG, np_{ij}	EG, χ_{ij}^2	CG, χ_{ij}^2
High (A)	23	6	10.41	10.58	2.01	1.98
Sufficient (B, C)	62	45	48.59	49.40	0.398	0.39
Medium (D, E)	32	57	51.07	51.92	0.504	0.49
Low (FX, F)	4	15	10.90	11.09	1.40	1.37
Total	121	123				$\chi_{emp}^2 = 8.57$

The obtained result provides grounds for rejecting the null hypothesis H_0 and accepting the alternative hypothesis H_1 regarding the positive impact of the developed application with augmented reality elements for teaching the measurement of metal hardness during laboratory work in the disciplines "Materials Science and Structural Materials Technology" and "Electrical Engineering Materials" on the level of students' academic achievements.

5. Conclusions

During remote learning or classroom learning during air raids, an important task is conducting laboratory work, where students must independently perform experiments on the relevant equipment, record, and process the necessary data. To address this task of teaching students how to measure the hardness of metals during laboratory work for the courses "Materials Science and Technology of Structural Materials" and "Electrical Engineering Materials", the authors developed and implemented a mobile application into the educational process.

The main objects of the laboratory session are hardness testers. The study presents the results of teaching metal hardness determination using the Brinell method. An electronic model of the HS-2M hardness tester, consisting of 9 parts, was developed in the CAD system. The mobile application with augmented reality elements of the marker type was developed in the Unity game engine. Augmented reality markers were created using the Vuforia platform. The application includes theoretical training information on working with hardness testers and a practical simulator. The main screen of the program features three buttons for learning how to determine hardness using different methods: Brinell, Rockwell, and Vickers.

The application is designed in such a way that students can view the electronic model of the hardness tester through augmented reality, choose the operating modes of the hardness tester, independently determine the diameter of the indenter's impression, and find the hardness value using special tables.

To verify the statistical significance of the developed application's use in the educational process, the Pearson's test was applied. The results of the pedagogical experiment demonstrated that the students in the experimental group achieved a quality success rate that exceeds the

control group's rate by 14%. This confirms the effectiveness of integrating the application into the educational process.

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