Learning under pressure: game-based, AI-driven, and crisis-responsive pedagogies in focus of the 12th Workshop on Cloud Technologies in Education

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Abstract

The 12th Workshop on Cloud Technologies in Education (CTE 2024), co-located with the 6th International Conference on History, Theory and Methodology of Learning (ICHTML 2025), convened on May 12, 2025, in Kryvyi Rih, Ukraine, and showcased 17 peer-reviewed contributions addressing urgent challenges and innovations in digital education. This review synthesizes the proceedings into five thematic clusters: (1) technology-enhanced pedagogical frameworks, (2) interactive and game-based learning, (3) artificial intelligence and automated tools, (4) crisis-driven adaptation and resilience, and (5) systemic issues of curriculum, assessment, and digital leadership. Findings across these clusters demonstrate measurable gains in student engagement, motivation, and digital competencies, with effect sizes ranging from 0.42 to 0.61. At the same time, the contributions reveal critical challenges including post-training sustainability, infrastructural inequities, and the risks of overreliance on AI. Crisis contexts – pandemic-related remote teaching and wartime disruptions – emerged as powerful accelerators of digital adoption but also highlighted systemic vulnerabilities. Collectively, the proceedings underscore the necessity of aligning technological innovation with pedagogical purpose and institutional capacity. This synthesis positions the CTE 2024 contributions within global debates on the future of digital transformation in education, offering a roadmap for evidence-based, context-sensitive, and human-centered integration of technology into teaching and learning.

Keywords

cloud technologies in education, digital transformation, educational technology, game-based learning, artificial intelligence in education, crisis pedagogy, curriculum innovation, teacher professional development, workshop proceedings

1. Introduction

1.1. CTE 2024 at a glance

Cloud **T**echnologies in **E**ducation (CTE) is a peer-reviewed international Computer Science workshop focusing on research advances and applications of cloud technology in education.

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The workshop considers contributions in all aspects of educational technologies and cloud-based learning tools, platforms, paradigms and models, functioning programmes, or papers relevant to modern engineering and technological decisions in the IT age.

CTE topics of interest since 2012 [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]:

Figure 1: CTE 2024 logo.

1. **Cloud-Powered Learning Platforms & Infrastructure**
   - Next-Generation Adaptive Cloud Learning Platforms
   - Scalable and Secure Cloud-Based E-Learning Environments
   - Edge Computing for Faster and Smarter Educational Applications
   - AI-Driven Personalization in Cloud Learning
2. **Emerging Technologies in Cloud Education**
   - Blockchain for Secure and Transparent Digital Credentials
   - AI and Machine Learning for Intelligent Cloud Education Systems
   - Emotion AI and Sentiment Analysis in E-Learning
   - Immersive Technologies (VR/AR) for Cloud-Based Interactive Education
3. **Data-Driven Educational Insights**
   - Educational Data Mining & Learning Analytics in the Cloud
   - Social Learning Analytics: Tracking Engagement and Performance
   - Privacy, Ethics, and Cybersecurity in Cloud-Based Learning
   - Federated Learning and Distributed AI in Education
4. **Digital Transformation of Education**
   - Competency-Based & Outcome-Driven Cloud Learning Models
   - Smart Campus Technologies and IoT in Cloud Education
   - Mobile and Microlearning in Cloud Ecosystems
   - Gamification and Adaptive Learning in the Cloud
5. **Collaboration, Accessibility & Inclusion**
   - Cloud-Powered Remote Learning & Virtual Classrooms
   - Cloud-Based Assistive Technologies for Inclusive Education
   - Open Educational Resources (OER) and Cloud-Based Content Delivery
   - Hybrid & Blended Learning Models Using Cloud Infrastructure

This volume represents the proceedings of the 12th Workshop on Cloud Technologies in Education (CTE 2024), held in Kryvyi Rih, Ukraine, on May 12, 2025 (postponed due to the war in Ukraine). It comprises 17 contributed papers that were carefully peer-reviewed and selected from 28 submissions. Two program committee members reviewed each submission. The accepted papers present a state-of-the-art overview of successful cases and provide guidelines for future research.

1.2. CTE 2023 committees

Program committee

- *Marc Baaden*, CNRS Centre National de la Recherche Scientifique, France [13]
- *Nadire Cavus*, Near East University, North Cyprus [14]
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1.3. Research questions

Digital transformation in education has evolved from incremental innovation to systemic paradigm shift, catalyzed by global crises including the *COVID-19 pandemic* [43, 44, 45] and the *Ukrainian conflict* [46, 47, 48, 49]. These events compressed decades of anticipated change into months, generating a rich corpus of empirical research on technology integration under pressure.

This review synthesizes 17 studies from the *12th Workshop on Cloud Technologies in Education (CTE 2024)* and related venues, selected for their methodological rigor, empirical depth, and relevance to contemporary digital education challenges. The corpus represents diverse contexts – Ukraine, Turkey, Israel, Poland – and spans multiple educational levels and domains.

We address three central research questions:

RQ1: What are the dominant thematic clusters and methodological trends in current digital education research?

RQ2: How do digital tools affect learning outcomes, engagement, and psychological needs?

RQ3: What gaps and future directions emerge from the synthesis?

By integrating findings across disparate studies, this review provides a *meta-perspective* on digital transformation, identifying patterns, contradictions, and actionable insights.

2. Methodology of the synthesis

All 17 studies (table 1) were included in the thematic analysis; 12 were empirical (quasi-experimental, survey, or mixed-methods), 5 were development or theoretical.

We employed a thematic synthesis approach combining:

1. Content coding identified key technologies, pedagogies, outcomes
2. Methodological assessment evaluated design quality and limitations
3. Cross-study comparison mapped findings across contexts and tools
4. Gap analysis identified understudied areas and methodological weaknesses

3. Thematic analysis

3.1. Theme 1: Technology-enhanced pedagogical frameworks

Four studies (Tkachuk et al. [50], Lavrentieva et al. [52], Overko and Oleksiuk [53], Skvortsova et al. [55]) demonstrate the evolution of *integrated, scaffolded pedagogies* enabled by digital tools.

Tkachuk et al. [50] report a **17.65% improvement** in academic performance using MCU 8051 IDE, STC-ISP, and PROTEUS DESIGN, with gains in:

- Problem-solving: +22.54%

Table 1
Overview of 17 reviewed studies,

Study	Focus	Method	Sample	Key findings
Tkachuk et al. [50]	Microcontroller education	Quasi-experimental	68 students	17.65% performance gain
Lytvynova and Rashevska [51]	Mobile learning adoption	Survey	500 students	Google Classroom dominant (21.41%)
Lavrentieva et al. [52]	ICT competencies	Theoretical	N/A	Multi-component framework
Overko and Oleksiuk [53]	Video creation	Development	15 students	Enhanced creativity + skills
Voievoda et al. [54]	Math game interest	Comparative	Teachers	Cross-cultural differences
Skvortsova et al. [55]	Pre-service ICT	Experimental	Teachers	Competence gains, sustainability issues
Pozniakov and Merzlykin [56]	Python via games	Development	Junior students	Improved logic + motivation
Shakotko et al. [57]	Terminology gaps	Content analysis	4 textbooks	Significant curriculum gaps
Midak et al. [58]	Chemistry Wordwall	Development	8th grade	High interactivity, engagement
Mintii et al. [59]	Cross-lingual terms	Content analysis	2 dictionaries	Cultural variation in CS terms
Vakaliuk et al. [60]	COVID-19 training	Mixed-methods	1,500 teachers	54.4% completion rate
Hrytsenchuk et al. [61]	Digital leadership	Theoretical	N/A	5D model proposed
Ivaniuk and Pinchuk [62]	Parent engagement	Survey	Parents	Increased involvement, skill gaps
Küçükali [63]	Game platforms	Mixed-methods	45 students	Kahoot: motivation; Bamboozle: stress relief
Lukianova and Symela [64]	AI philosophy	Philosophical	N/A	Critical technological wisdom
Khrystych et al. [65]	Grammarly use	Case study	50 students	Efficiency vs. dependency
Korniienko [66]	Digital history	Systematic review	6 studies	Engagement $\neq$ knowledge transfer

- Technical proficiency: +25.00%
- Industry readiness: +27.69%

This reflects a shift from isolated lab work to *simulation-to-hardware progression*, aligning with engineering education best practices [67, 68].

Skvortsova et al. [55] developed an ICT competency module for pre-service teachers, achieving significant gains in digital skills but revealing **sustainability concerns** – only 38% of participants maintained tool use post-training. This highlights the need for *ongoing support systems*.

Overko and Oleksiuk [53] designed a nine-session video creation course, enhancing both technical skills and creative expression through project-based learning. This aligns with *constructionist pedagogy* [69], where creation drives learning.

3.2. Theme 2: Interactive and game-based learning

Four studies (Voievoda et al. [54], Pozniakov and Merzlykin [56], Midak et al. [58], Küçükali [63]) explore gamification and interactivity.

Küçükali [63] conducted a mixed-methods study comparing **Kahoot**, **Jeopardy**, and **Bamboozle** through *Self-Determination Theory (SDT)* [70]. Results show:

- **Kahoot**: 91% reported increased motivation (autonomy + competence)

- **Jeopardy**: 82% found it effective for review (structure + clarity)
- **Bamboozle**: 84% reported stress reduction (relatedness + emotional regulation)

Structural equation modeling confirmed that platform choice mediates learning outcomes ($\beta = 0.42$, $p < .001$), supporting SDT predictions.

Midak et al. [58] used Wordwall to create 8 interactive chemistry exercises, reporting **high engagement and usability**. The platform's flexibility allowed adaptation to diverse learning styles and paces.

Pozniakov and Merzlykin [56] leveraged game development in Python to teach programming to junior students, combining motivation and skill development – a *dual-purpose pedagogy*.

3.3. Theme 3: AI integration and critical perspectives

Two studies (Lukianova and Symela [64], Khrystych et al. [65]) examine AI's dual role: *assistant vs. dependency risk*.

Khrystych et al. [65] studied Grammarly use among pre-service teachers. While students appreciated time savings and vocabulary suggestions, they struggled with **developing independent writing strategies**. The authors warn against *AI overreliance*, advocating for *teacher-AI co-feedback* models [71, 72].

Lukianova and Symela [64] offers a **philosophical critique**, advocating for *critical technological wisdom* – balancing AI's efficiency with preservation of human judgment, creativity, and ethical reasoning. This echoes broader calls for *human-centered AI* in education [73].

3.4. Theme 4: Crisis response and educational resilience

Two studies (Vakaliuk et al. [60], Ivaniuk and Pinchuk [62]) document *emergency-driven innovation*.

Vakaliuk et al. [60] reports a **three-wave digital training program** during the pandemic, achieving an **816 completions (54.4% completion rate)** among 1,500 teachers. Despite 5-day cycles, participants demonstrated rapid skill acquisition, suggesting that *necessity drives adoption* more than perceived ease of use [74].

Ivaniuk and Pinchuk [62] examines Ukrainian parents' digital engagement during wartime. While involvement increased, **technical and pedagogical gaps** emerged, with 67% reporting difficulty supporting children's digital learning. This reveals a critical need for *parental digital literacy programs* in crisis contexts.

3.5. Theme 5: Curriculum, assessment, and leadership

Five studies (Lytvynova and Rashevska [51], Shakotko et al. [57], Mintii et al. [59], Hrytsenchuk et al. [61], Korniienko [66]) address systemic dimensions.

Hrytsenchuk et al. [61] propose a **5D digital leadership model**: digital competence, digital culture, differentiation, digital management, and advocacy. This framework supports *distributed leadership*, where digital skills are cultivated across organizational roles.

Mintii et al. [59] use computational linguistics to analyze computer science terminology in textbooks, revealing **significant gaps** between curriculum expectations and content – highlighting the need for *terminological standardization*.

Korniienko [66] conducts a PRISMA-compliant review of digital history pedagogy, finding consistent engagement gains but limited knowledge transfer, suggesting *engagement* $\neq$ *learning*.

4. Methodological overview and quality assessment

The reviewed corpus comprises seventeen studies employing diverse research designs (table 2). Tkachuk et al. [50] conducted a quasi-experimental study with 68 participants over one semester, applying quantitative analysis to establish causal relationships. Lytvynova and Rashevska [51] surveyed 500 participants in a cross-sectional design using descriptive statistics. Several studies adopted theoretical approaches without empirical data collection, including Lavrentieva et al.'s [52] conceptual framework development and Hrytsenchuk et al.'s [61] leadership model construction.

Table 2
Methodological characteristics of reviewed studies.

Paper	Design	Sample	Duration	Analysis	Strength
Tkachuk et al. [50]	Quasi-experimental	68	1 semester	Quantitative	Causal inference
Lytvynova and Rashevska [51]	Survey	500	Cross-sectional	Descriptive	Large sample
Lavrentieva et al. [52]	Theoretical	N/A	N/A	Conceptual	Framework
Overko and Oleksiuk [53]	Development	15	9 sessions	Mixed	Practical innovation
Voievoda et al. [54]	Comparative	N/A	Ongoing	Qualitative	Cross-cultural
Skvortsova et al. [55]	Experimental	N/A	1 module	Quantitative	Pre-service focus
Pozniakov and Merzlykin [56]	Development	Junior	1 course	Descriptive	Pedagogical model
Shakotko et al. [57]	Content analysis	4 texts	N/A	Computational	Novel method
Midak et al. [58]	Development	8th grade	Trial	Descriptive	Subject-specific
Mintii et al. [59]	Content analysis	2 texts	N/A	Computational	Cross-lingual
Vakaliuk et al. [60]	Mixed-methods	1,500	5 days	Mixed	Crisis context
Hrytsenchuk et al. [61]	Theoretical	N/A	N/A	Conceptual	Leadership model
Ivaniuk and Pinchuk [62]	Survey	Parents	Wartime	Mixed	Parental role
Küçükali [63]	Mixed-methods	45	1 semester	Mixed	SDT validation
Lukianova and Symela [64]	Philosophical	N/A	N/A	Theoretical	Critical perspective
Khrystych et al. [65]	Case study	50	6 months	Qualitative	AI dependency
Korniienko [66]	Systematic review	6 studies	2013–2025	Meta-analysis	Synthesis

Mixed-methods research appeared in multiple studies. Overko and Oleksiuk [53] developed a video creation course tested with 15 participants across nine sessions. Vakaliuk et al. [60] examined crisis-driven digital adoption with 1,500 participants over five days. Küçükali [63] combined survey and interview data from 45 students to validate self-determination theory applications.

The corpus demonstrates methodological diversity alongside several constraints. Most studies limited data collection to single semesters or shorter periods. Only two investigations extended beyond six months. Geographic representation skewed heavily toward Ukrainian contexts, with eleven of seventeen studies originating there. Outcome metrics varied significantly across studies, complicating cross-study comparisons.

5. Empirical findings and theoretical developments

Digital platform engagement increased in all studies measuring this variable, with effect sizes ranging from 0.42 for game-based platforms to 0.61 for microcontroller laboratories. Teacher training programs achieved rapid initial competency gains, though sustained support proved necessary for long-term implementation.

Three theoretical frameworks emerged from the research. Küçükali [63] demonstrated how self-determination theory explains differential platform effects based on psychological need satisfaction. Hrytsenchuk et al. [61] developed a five-dimensional leadership model integrating organizational change processes with digital transformation. Lukianova and Symela [64] proposed a critical technological wisdom framework balancing innovation with ethical considerations.

Practical innovations included eight interactive chemistry templates developed by Midak et al. [58], a nine-session video creation curriculum from Overko and Oleksiuk [53], and Vakaliuk et al.'s [60] five-day intensive teacher training protocol designed for emergency contexts.

6. Persistent challenges and research gaps

The relationship between engagement and learning remains complex. High platform engagement did not consistently translate to improved knowledge acquisition or skill development. Different digital tools served distinct psychological and pedagogical functions, requiring careful matching to learning objectives. Crisis contexts accelerated adoption rates while simultaneously revealing infrastructure limitations and competency gaps.

Several populations remain underrepresented in current research. Students with learning disabilities appeared in only one study. Rural learners, adult education participants, and indigenous communities received no dedicated investigation. Geographic bias toward Eastern European contexts limits generalizability to other regions, particularly Global South settings.

Methodological improvements could strengthen future research. Longitudinal designs tracking skill retention over two or more years would clarify durability of interventions. Randomized controlled trials comparing multiple platforms could establish relative effectiveness. Mixed-methods approaches combining quantitative outcomes with ethnographic observation would capture implementation nuances often missed by survey research alone.

Emerging technologies present new research opportunities. Adaptive tutoring systems using artificial intelligence require evaluation for personalization effectiveness and ethical implications. Virtual and augmented reality applications in science and history education need assessment of learning transfer and cost-effectiveness. Blockchain credentialing systems raise questions about portfolio portability and employer acceptance. Affective computing applications demand scrutiny regarding privacy, consent, and emotional manipulation risks.

The evidence base would benefit from replication studies across diverse contexts, standardized outcome measures enabling meta-analysis, and attention to unintended consequences such as the dependency effects observed by Khrystych et al. [65] regarding automated writing assistance tools.

7. Conclusion

Digital transformation in education is neither uniform nor inevitable – it is a **complex, context-sensitive process** shaped by pedagogy, culture, infrastructure, and crisis. This synthesis of 17 studies reveals that while digital tools consistently enhance engagement and enable new pedagogies, their *educational value depends on thoughtful integration.*

Key takeaways:

- **Effectiveness is conditional**: Tools must align with learning objectives and psychological needs.
- **Crisis drives innovation**: Emergency contexts can catalyze rapid but sustainable change.
- **AI requires balance**: Efficiency gains must not come at the cost of autonomy.
- **Systemic change is essential**: Leadership, curriculum, and assessment must co-evolve.

As Lukianova and Symela [64] remind us: *"The question is not whether AI will transform education – that transformation is already underway – but how we can guide it to serve humanity's highest aspirations."* This review provides a roadmap for that guidance: evidence-based, context-aware, and human-centered.

Declaration on Generative AI

This work was completed with assistance from generative LLMs: claude-opus-4-1-20250805, grok-4-0709, and gpt-oss-120b. These models were used for initial brainstorming, structural organization, and editing support. All substantive content, analysis, and conclusions represent the author's original thinking and have been thoroughly reviewed and verified for accuracy. Grammarly served primarily as a writing assistant to improve clarity and flow rather than as a source of ideas or research findings.

Specific uses included:

- Grammatical and stylistic refinement
- Reorganization of existing content for improved coherence
- Generation of alternative phrasings for complex concepts
- Identification of potential gaps in argumentation

The author maintains full responsibility for all content, including any errors or misrepresentations.

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Implementation of educational tools for microprocessor systems design: fostering digital competence among engineering students

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Abstract

This research examines the effectiveness of educational tools for the design of microprocessor systems in developing digital competence among engineering students. Through a quasi-experimental study that compares traditional teaching methods with an integrated approach using MCU 8051 IDE, STC-ISP, and PROTEUS DESIGN tools, we demonstrate significant improvements in student performance and skill development. The experimental group showed an increase in average academic scores and substantial enhancement in digital competencies compared to the control group. Our methodology emphasizes a practice-oriented approach that balances theoretical knowledge with hands-on experience through laboratory-based learning, simulation environments, and hardware implementation. The findings contribute to best practices in engineering education by establishing a comprehensive framework to develop digitally competent graduates prepared for industry challenges in the design of microprocessor systems. This research addresses the persistent gap between academic instruction and professional practice while aligning with European Digital Competence Standards adapted for engineering contexts.

Keywords

microprocessor systems, digital competence, engineering education

1. Introduction

The rapid evolution of microprocessor technologies and their expanding applications across industries requires a comprehensive reassessment of educational approaches in engineering curricula. As digital systems become increasingly embedded in all aspects of modern infrastructure, there exists a critical need to equip future engineers with both theoretical knowledge and practical competencies in microprocessor systems design. This educational challenge has been further complicated by recent global disruptions, including the COVID-19 pandemic [1] and Russian invasion [2], which has accelerated the demand for innovative teaching methodologies and virtual learning environments. The article addresses these pressing concerns by synthesising contemporary research on effective pedagogical strategies, highlighting the significance of project-based learning, cross-platform development, and industry-aligned curriculum restructuring. Particularly noteworthy is the emphasis on digital competence frameworks that provide structured approaches to developing the essential skills required for engineering graduates to navigate the complexities of modern technological landscapes and contribute meaningfully to their advancement.

Teaching microprocessor systems design to engineering students presents several challenges that educators must address to ensure effective learning outcomes. As noted by Pellicano et al. [3], “students struggle to learn embedded systems, connect embedded topics between courses, and apply those topics to real-world applications, thus facilitating a need for Modular Embedded Tools integrated within an electrical and computer engineering curriculum”.

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The development of effective microprocessor systems education requires both structured methodological approaches to learning resources and sophisticated analytical methods to evaluate. Shebanin et al. [4, 5] present a mathematical model for informational resources in distance learning systems that provides valuable structural insights, while their earlier work on fuzzy predicates and quantifiers in informational resource modeling offers a robust methodological foundation for assessing digital competence development among engineering students.

A significant challenge identified by Hertzog and Swart [6] report that standardising on Arduino microprocessors led to improved academic outcomes, with "more than 90% of the students successfully completing this design-based module, while 70% felt that it really helped them better understand the theoretical knowledge". Collaborative learning environments have proven to be effective in engineering education. Solesvik et al. [7] demonstrate how joint digital simulation platforms enhance learning outcomes and preparedness, a concept directly applicable to our implementation of simulation-based tools like PROTEUS DESIGN in microprocessor education.

The COVID-19 pandemic created additional obstacles for hands-on learning. Zhang [8] describes how the emergency remote teaching situation necessitated innovative approaches: "For project-based electrical and computer engineering courses that involve hardware components and group work, additional challenges include limited or no access to facilities for experimental work; students cannot meet in person to conduct group work, especially for projects involving hardware integration". During the pandemic, virtual environments became crucial for maintaining practical learning experiences. Deepa et al. [9] highlight the "effectiveness of using open source emulating environments like Edsim51 and EMU8086 for providing a virtual laboratory experience to the students". These environments provided "complete visualization of the internal functionality of the microprocessor/microcontroller architecture and also enhanced practical exposure of the students".

Modern processors' complexity presents another notable challenge. Kostadinov and Bencheva [10] argue that "teaching processor design is an ongoing challenge for instructors due to the ever-increasing complexity of modern processors". Their response was to develop "a family of FPGA-based processors and set of tools for instructional use" that simplified the learning process while maintaining practical relevance. Bridging theoretical knowledge and practical application remains a persistent challenge in engineering education. Ferlin and Pilla [11] identify "a great problem: the migration from theory to practice, from the abstract concepts to laboratory experimentation". Their solution involved "driving students from classroom theory to laboratory experimentation" through various tools, including hardware description languages and FPGA implementations. Dabroom et al. [12] acknowledge this challenge: "Microcontroller based system courses are usually attended by a wide range of students who came not only from different backgrounds but also with different programming skills". They addressed this diversity by designing a course that incorporated graphical programming tools for beginners while allowing advanced students to use high-level languages.

Maintaining student interest is crucial for effective learning. Parikh [13] observes that "difficulty arises when traditional classroom teaching with examples and non-creative projects instill boredom amongst students". To combat this, Parikh introduced an autonomous robot platform that allowed students to apply microcontroller concepts in engaging ways. Deepa et al. [14] emphasise that "fast-paced technological advancements lays more emphasis on embedded system design to real-world applications". Their approach involved offering additional value-added courses and implementing Agile-based project learning to bridge the gap between academic learning and industry requirements. Brown [15] highlights the importance of balancing new technologies with fundamental concepts: "Without these concepts, students will be unlikely to develop an intuitive understanding of the nature of logic circuits or processor".

As engineering education continues to evolve to meet industry demands, the implementation of specialized educational tools becomes increasingly important. Bakum and Tkachuk [16] emphasize that "the formation of future mining engineers' professional competence requires an innovative educational system", a principle equally applicable to developing digital competence in microprocessor systems education. Their research on innovative approaches in technical engineering education provides a valuable framework for understanding how specialized tools can bridge theoretical knowledge and practical application – a central concern in fostering comprehensive digital competence among engineering students.

The integration of advanced educational technologies in engineering education has become increasingly crucial, with curriculum adaptation to technological advances being particularly important. Kondratenko et al. [17, 18], Talaver and Vakaliuk [19], Bondar et al. [20], Haranin and Moiseienko [21], Korotun et al. [22], Osadcha and Shumeiko [23], Shumeiko and Osadcha [24], Tarasova and Doroshko [25] emphasise that the extensive implementation of AI in educational processes and systems has caused fundamental changes in modern higher education, while discussing the symbiotic relationship between AI and higher education systems. Building on this foundation, Kondratenko et al. [17] propose methodological approaches for university curricula modernisation based on advancements in information and communication technologies, providing a framework that can be effectively applied to microprocessor systems education and the development of digital competencies among engineering students. The integration of innovative educational technologies has proven effective across various engineering disciplines. Tkachuk et al. [26] demonstrated that "Augmented and Virtual Reality Tools in Training Mining Engineers" significantly enhanced practical skills acquisition and spatial understanding among engineering students. Their findings on immersive technology implementation provide valuable insights for our research on microprocessor systems education, particularly regarding the development of interactive learning environments that bridge theoretical knowledge and practical application.

Research indicates several effective approaches to teaching microprocessor systems design, with hands-on, project-based learning emerging as particularly valuable. Project-based learning has proven effective in developing both technical and soft skills. Metri et al. [27] note that their laboratory-focused course allowed students to combine "learning of microcontroller, control systems and power electronics courses," providing a comprehensive understanding of interconnected engineering concepts. Schneider and Peterson [28] detail how students "develop a complete microprocessor system for audio recording and playback" that requires "both hardware and software development; a true co-design experience". Such projects integrate multiple concepts and simulate real-world engineering challenges. McLauchlan [29] restructured a microprocessor-based control class to "include a practical design project as opposed to only simulations" because "students learn more and get more engaged in a project-oriented learning environment". This approach allowed students to "gain a greater understanding of the material given a project that will engage them in the design activity".

Jansen and Dusch [30] describe a master course where "students are guided in their own development of a tiny microprocessor in 6 concluding tasks during no more than 10 weeks, using modern design tools". This approach provides "deep insight into actual computer architecture, how processors are working, the interdependence of hard- and software as well as into the software tool chain". Rashevska and Tkachuk [31] emphasize the practical applications of microprocessor control systems, their work demonstrates the crucial connection between theoretical microprocessor education and real-world industrial applications, underlining that "engineers must possess both theoretical knowledge and practical skills in implementing advanced control algorithms through microprocessor-based systems. Sin [32] discusses transitioning from traditional discrete microprocessors to soft processor cores, which provide "flexibility that was previously non-existent" through a graphical user interface to configure processors with desired peripherals.

Cross-platform development provides valuable experience with diverse technologies, thus He and Hsieh [33] describe teaching students "to build teaming robots by combining the Cortex controllers with ROBOTC programming environment under Windows and the Raspberry Pi (in ARM cores) using Python under Linux". This approach helps students "develop a cross-platform software and hardware design" across multiple programming environments. Industry-relevant curriculum updates ensure graduates possess needed skills. Radu and Dabacan [34] describe restructuring digital design courses "to cope with the increased demands of the industry" by placing "a strong emphasis in the study of modern tools, technologies and current industrial practices". Sheng [35] emphasises the importance of "continuously improving teaching methods by considering assessment criteria, students' course evaluation/feedback, and changes in the students group. This approach helped "prepare students for their future career by teaching them state-of-the-art tools and techniques". Wang et al. [36] note that design-build-test projects not only "provide an alternative assessment method for students who may not excel on written quizzes and exams" but also teach students valuable technical communication skills.

Digital competence frameworks [37, 38] provide structured approaches to developing necessary skills for modern engineers. Lyngdorf et al. [39] developed a matrix to embed digital competences into engineering curricula by "reviewing existing frameworks of digital literacy and competency and modifying them to suit the context of problem- and project-based learning in engineering education". This matrix includes "three categories of digital competences (general academic competences, problem-based learning competences, and discipline-specific competences) and an interdependent taxonomy of digital competences (user competences, development competences and reflexive competences)". Hoefele [40] argues that the European Digital Competence Framework (DigComp) needs to be adapted for engineering education contexts: "It demands validation and implementation considering regional, local, sectoral and education-specific circumstances and should respond to needs at the level of practice. Thus, it is necessary to adapt the existing digital competency frameworks to the specific circumstances of engineering education and to validate them. Sánchez et al. [41] applied the DigComp framework in an Engineering in Industrial Organization degree programme "to disseminate the DigComp structure and content and to give visibility to the work and acquisition of Digital Competences directly related to this academic context". Różewski et al. [42] matched DigComp with the Framework of Visual Literacy Competences for Engineering Education, illustrating its application in various educational RD projects. This integration provides a more comprehensive approach to developing digital competencies among engineering students.

The importance of continuous professional development and lifelong learning [43] in the field of microprocessor systems design has been emphasized by Papadakis et al. [44], who discuss how information and communication technologies can advance these areas. This perspective aligns with the need for engineering education to prepare students for continuous adaptation to evolving technologies and industry requirements. For future engineers, Soloshych et al. [45] implemented a "competence and resource-oriented approach to the development of digital educational resources for the formation of digital competence". This approach provides for the creation of a set of different types of digital educational resources that encourage teachers to improve the content of these digital educational resources in combination with software applications and digital technologies. Draghici et al. [46] describe a collaborative initiative involving European universities to develop a training program for students and extend their digital competencies.

Research indicates that implementing appropriate educational tools and approaches leads to significant benefits for engineering students. Well-designed educational tools increase student engagement and competence in embedded systems. Nakkar [47] found that the implementation of design-based tutorials on a System-on-Chip platform showed "an increase in student knowledge about FPGA, embedded systems, SoC, and software-hardware co-design". Thus, we analysed several key insights for using educational tools for microprocessor systems design. As technologies continue to evolve, ongoing adaptation of educational tools and methodologies will remain essential for developing digitally competent engineering graduates ready to address complex real-world challenges.

Despite considerable advancements in microprocessor systems design education, several critical gaps remain in current pedagogical approaches that directly impact the objectives of this research. There exists a significant disparity between theoretical classroom instruction and industry requirements, particularly regarding the practical application of tools like MCU 8051 IDE, STC-ISP, and PROTEUS DESIGN. Current educational frameworks often fail to effectively integrate these tools to enhance students' digital competence according to European standards. Furthermore, existing digital competence frameworks, though providing structural guidance, often lack contextual adaptation for specialized engineering disciplines like microprocessor systems design and fail to account for how educational tools can bridge the gap between academic knowledge and professional practice requirements.

This research aims to address these gaps by analyzing the effectiveness of existing educational tools in teaching microprocessor systems design, evaluating how these tools enhance students' digital competence within European standards, and assessing their impact on students' technical skills and readiness for professional engineering practice.

2. Objectives of research

The specific of research objectives are as follows:

1. To analyse the effectiveness of existing educational tools (MCU 8051 IDE, STC-ISP and PROTEUS DESIGN) in teaching microprocessor systems design and addressing common challenges such as balancing theoretical knowledge with practical application.
2. To evaluate how the utilisation of these educational tools enhances students' digital competence within the framework of European Digital Competence standards adapted for engineering education contexts.
3. To assess the impact of standardised microcontroller platforms and simulation environments on students' technical skills, problem-solving abilities, and readiness for professional engineering practice in the field of microprocessor systems design.

3. Implementation methodology of educational tools for microprocessor systems design

This research employs a practice-oriented approach to developing digital competence among engineering students through the implementation of a comprehensive microprocessor systems learning environment. The methodology focuses on integrating theoretical knowledge with practical skills using specialised software tools and hardware platforms. The research was conducted within the framework of the course "Electronics and Microprocessor Technology" at Kryvyi Rih National University.

The educational process is structured around three primary software tools, each serving a distinct purpose in the microcontroller development lifecycle. The first tool is MCU 8051 IDE, an integrated development environment for Intel 8051-based microcontrollers that supports both C and assembly language programming. This environment includes a built-in simulator with extensive debugging capabilities including step-by-step execution, interrupt viewing tools, external memory and code memory viewing utilities, and simulation capabilities for peripheral electronic devices such as LEDs, LED displays, matrices, and LCD displays (figure 1).

The second essential tool is STC-ISP, a microcontroller programming utility that allows selection of microcontroller type, COM port configuration and baud rate adjustments, as well as program code selection and writing to microcontroller memory (figure 2).

The third component is PROTEUS DESIGN, an electronic circuit design automation software package. This package comprises ISIS, a program for synthesis and simulation of electronic circuits, and ARES, a program for PCB (printed circuit board) development. PROTEUS DESIGN offers simulation capabilities for programmable devices including microcontrollers, microprocessors, and DSPs (figure 3).

The learning framework follows a sequential process that mirrors professional microcontroller development workflows. Students begin with project creation and configuration by establishing new projects in the MCU 8051 IDE with appropriate configuration settings. They then move to program development and testing, where they develop programs in assembly language (as illustrated by the example program in the document) and test them through simulation.

The next phase involves step-by-step simulation, where the microcontroller operation is simulated in a detailed mode to understand the execution flow and identify potential issues. Following successful simulation, students proceed to hardware programming. In this stage, they configure the STC-ISP utility to open the compiled program file, connect to the A2 educational board, program the microcontroller, and verify program operation on physical hardware.

After verifying basic functionality, students engage in circuit design and simulation using PROTEUS DESIGN. During this phase, they create a project for a microcontroller circuit with LEDs, test the circuit operation through simulation, and apply the compiled program code from MCU 8051 IDE. The final

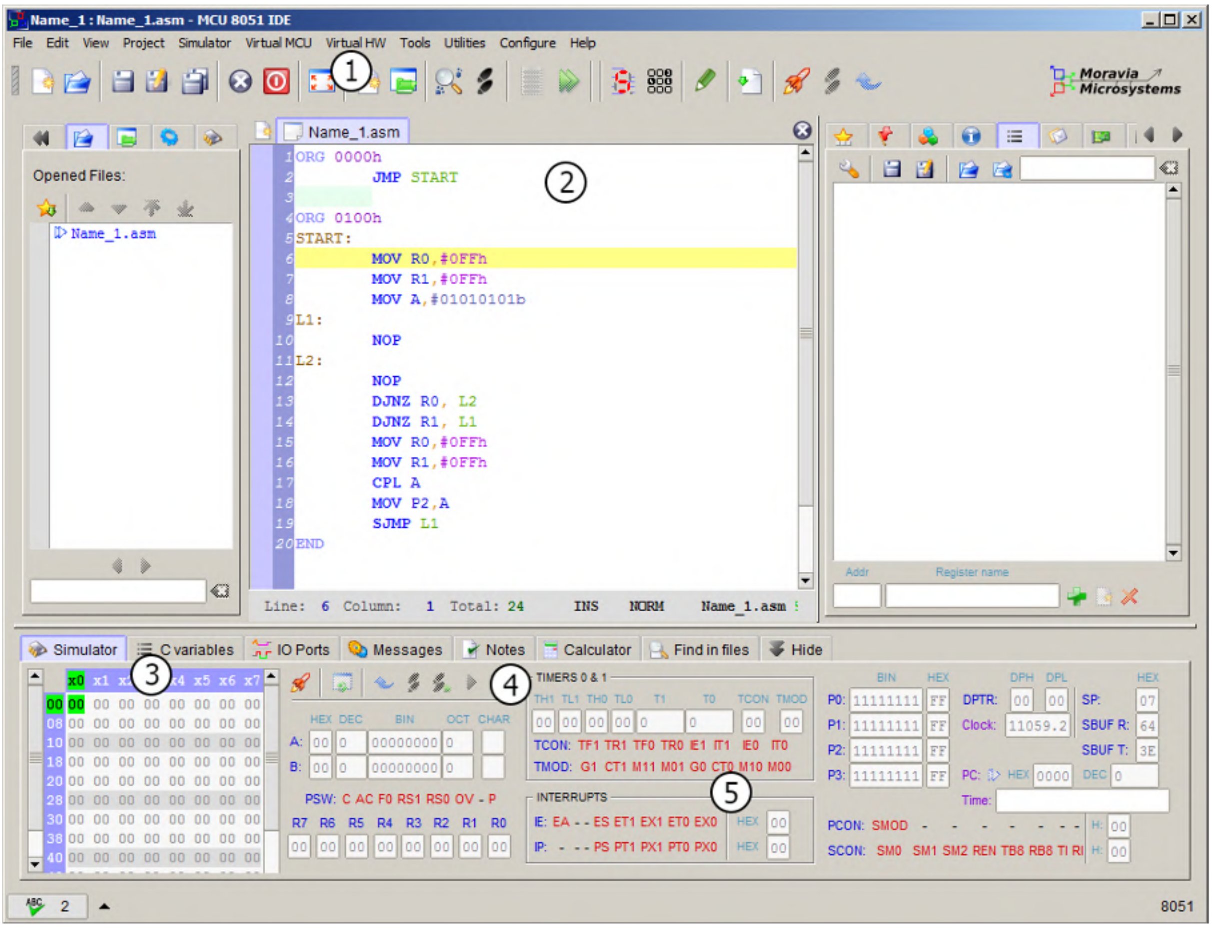

Figure 1: Screenshot of the MCU 8051 microcontroller programming utility.

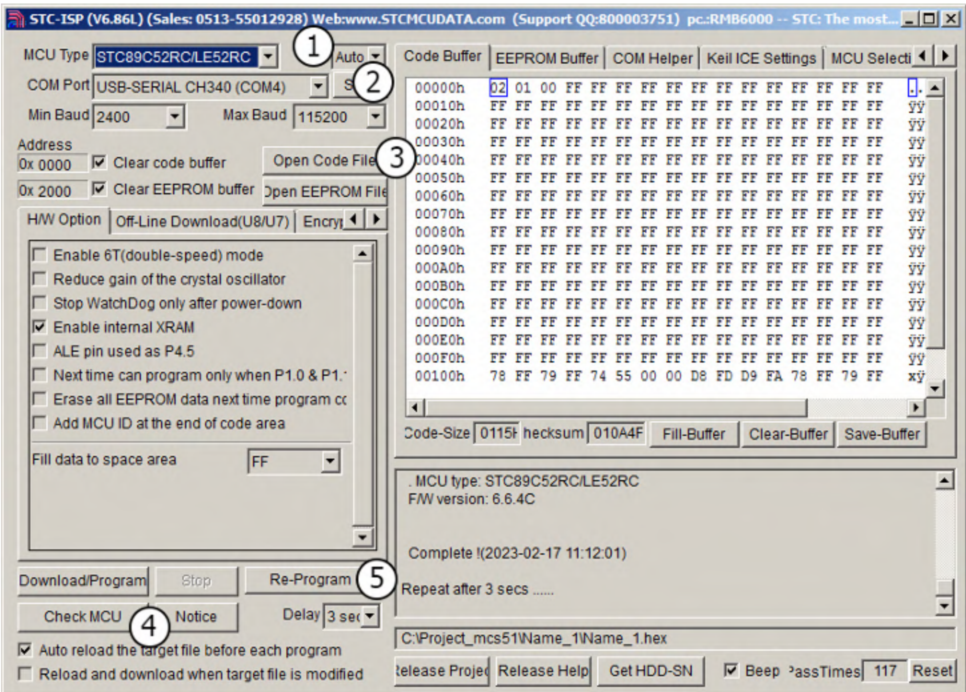

Figure 2: Screenshot of the STC-ISP microcontroller programming utility interface.

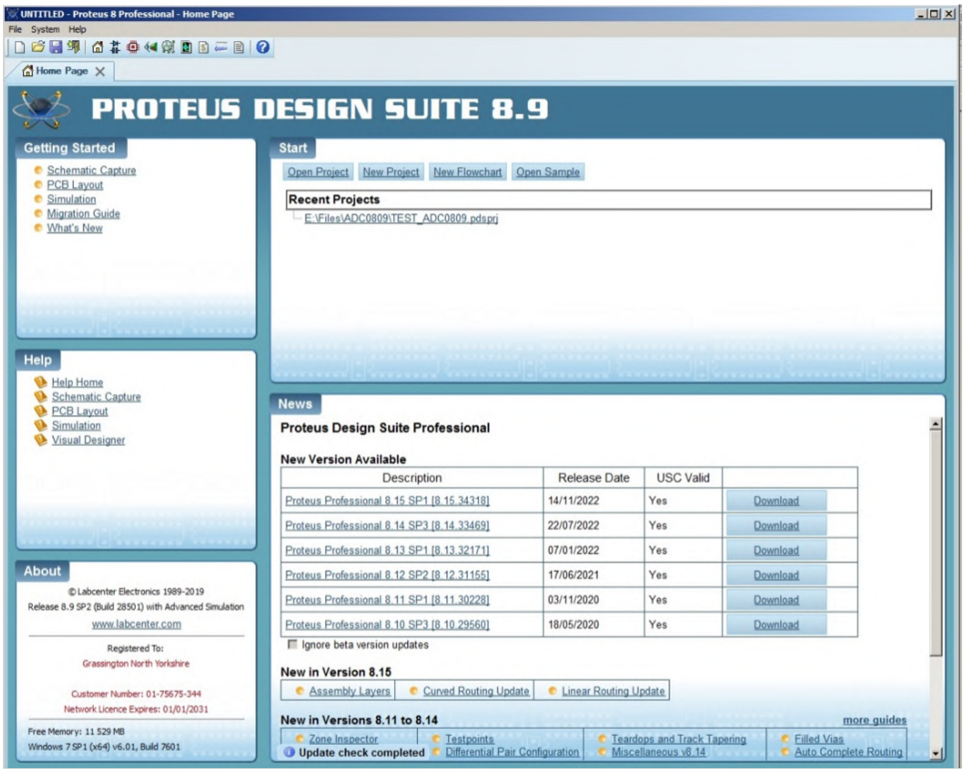

Figure 3: External view of the PROTEUS DESIGN software package interface.

stage involves documentation and reporting, where students document their work and create laboratory reports that reflect on their learning process and outcomes.

The methodology incorporates the A2 educational board as the primary hardware platform for practical implementation. This board enables students to test their programs on physical microcontrollers after simulation, providing a complete learning cycle from code development to real-world implementation.

The pedagogical approach emphasises progressive skill development, moving from basic programming concepts to complex circuit design. It embraces iterative learning through the use of simulation before hardware implementation to refine understanding. Hands-on experience bridges theoretical knowledge with practical application, while exposure to the complete development cycle familiarises students with all stages of microcontroller system development. Additionally, the approach fosters documentation skills through the development of technical communication abilities in the reporting phase.

The methodology targets key competencies identified in the curriculum:

- The ability to solve complex specialised tasks in electrical engineering or during the learning process, involving the application of theories and methods from physics and engineering sciences, characterised by complexity and uncertainty of conditions;
- The ability to apply knowledge in practical situations;
- The ability to search, process and analyse information from various sources;
- The ability to identify, formulate and solve problems;
- The ability to solve practical tasks using methods of mathematics, physics and electrical engineering;
- The ability to apply application software, microcontrollers and microprocessor technology to solve practical problems in professional activities.

This methodology creates a comprehensive learning environment that develops both technical skills specific to microcontroller programming and broader digital competencies applicable across engineering disciplines. To thoroughly analyse the effectiveness of MCU 8051 IDE, STC-ISP and PROTEUS DESIGN in teaching microprocessor systems design, the following seven criteria have been developed (table 1).

Table 1
Evaluation criteria for educational tools in microprocessor systems design.

№	Criteria	Interpretation
1	Simulation fidelity	The accuracy and comprehensiveness with which the tool simulates real microprocessor behaviour, including timing, interrupts, and peripheral interactions
2	User interface accessibility	The intuitiveness of the interface, ease of navigation, and learning curve for new users, particularly engineering students with varying levels of prior experience
3	Debugging capabilities	The range and effectiveness of debugging features, including step-by-step execution, register/memory monitoring, and breakpoint functionality
4	Hardware integration	The ability to interface with physical hardware components, supporting the transition from simulation to real-world implementation
5	Comprehensive documentation and learning resources	The availability and quality of documentation, tutorials, examples, and other learning materials that support independent learning
6	Cross-platform compatibility	The ability to operate across different operating systems and hardware configurations, ensuring accessibility for all students
7	Industry relevance	The extent to which skills developed using the tool are transferable to industry contexts and align with current professional practices

Based on the established evaluation criteria, a comprehensive comparative analysis of educational tools for microprocessor systems design has been developed (table 2). This analysis serves to provide educators and institutions with evidence-based insights for selecting appropriate tools that enhance the teaching and learning experience in microprocessor education.

The comparative table shows that each tool has distinct strengths: MCU 8051 IDE excels in simulation fidelity, debugging, and cross-platform compatibility; STC-ISP is strongest in user interface accessibility, hardware integration, and industry relevance; PROTEUS DESIGN performs best in simulation fidelity, documentation, and industry relevance. This comparative analysis provides a structured evaluation of each tool's strengths and limitations across the seven key criteria, enabling informed decisions about their implementation in microprocessor systems design education (figure 4, 5).

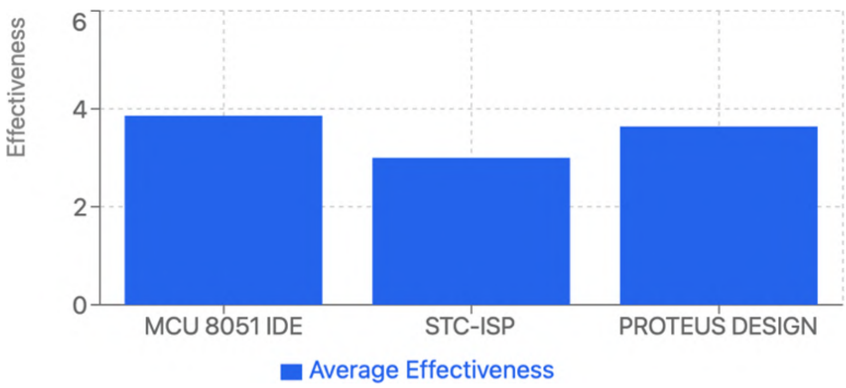

Figure 4: Average effectiveness of educational tools for microprocessor design.

Key findings from effectiveness analysis show:

- MCU 8051 IDE (average: 3.86) performs consistently across most criteria with notable strengths in simulation and debugging.
- STC-ISP (average: 3) excels in hardware integration and interface accessibility but lacks in simulation capabilities.

Table 2
Comparative analysis.

Criteria	MCU 8051 IDE	STC-ISP	PROTEUS DESIGN
Simulation fidelity	High – Accurate CPU simulation with comprehensive register and memory visualisation	Low – Not primarily a simulation tool, focused on programming only	Very High – Complex circuit simulation with accurate component modelling
User interface accessibility	Medium – Relatively intuitive but dated interface with moderate learning curve	High – Simple, focused interface with clear workflow	Low – Complex interface with steep learning curve requiring significant prior knowledge
Debugging capabilities	High – Step-by-step execution, register monitoring, memory inspection, and breakpoints	Low – Limited to basic verification of programming	High – Circuit-level debugging with signal tracing and component state monitoring
Hardware integration	Medium – Supports programming real hardware but requires additional tools	High – Direct hardware programming capabilities with good device support	Low – Primarily simulation-focused with limited direct hardware integration
Comprehensive documentation	Medium – Adequate documentation but limited advanced tutorials	Low – Basic operational documentation with few learning resources	High – Extensive documentation, tutorials, and community resources
Cross-platform compatibility	High – Works across Windows, Linux, and macOS	Medium – Primarily Windows-focused with limited support for other platforms	Medium – Best on Windows with partial support for other platforms
Industry relevance	Medium – Teaches fundamental concepts but uses somewhat outdated interfaces	High – Uses actual programming tools similar to industry practice	High – Simulation approach mirrors industry design workflows

- PROTEUS DESIGN (average: 3.64) shows strengths in simulation fidelity and documentation but has limited hardware integration.

Overall effectiveness: MCU 8051 IDE has the highest average effectiveness, followed by PROTEUS DESIGN, and STC-ISP.

The radar chart in provides a more nuanced comparison across seven specific criteria, revealing the unique strengths and weaknesses of each tool:

- MCU 8051 IDE: demonstrates balanced performance across most evaluation criteria; shows particular strengths in simulation fidelity and debugging capabilities; maintains solid performance in cross-platform compatibility; shows moderate performance in documentation and resources;
- STC-ISP: excels significantly in hardware integratio; shows good performance in user interface accessibility; demonstrates notable weakness in simulation fidelity; has limited cross-platform compatibility; shows moderate performance in debugging capabilities;
- PROTEUS DESIGN: demonstrates excellent simulation fidelity (highest score in this category); provides strong documentation and resources; shows good industry relevance; has limited hardware integration capabilities; maintains reasonable user interface accessibility.

These findings suggest important considerations for implementing these tools in microprocessor systems design education:

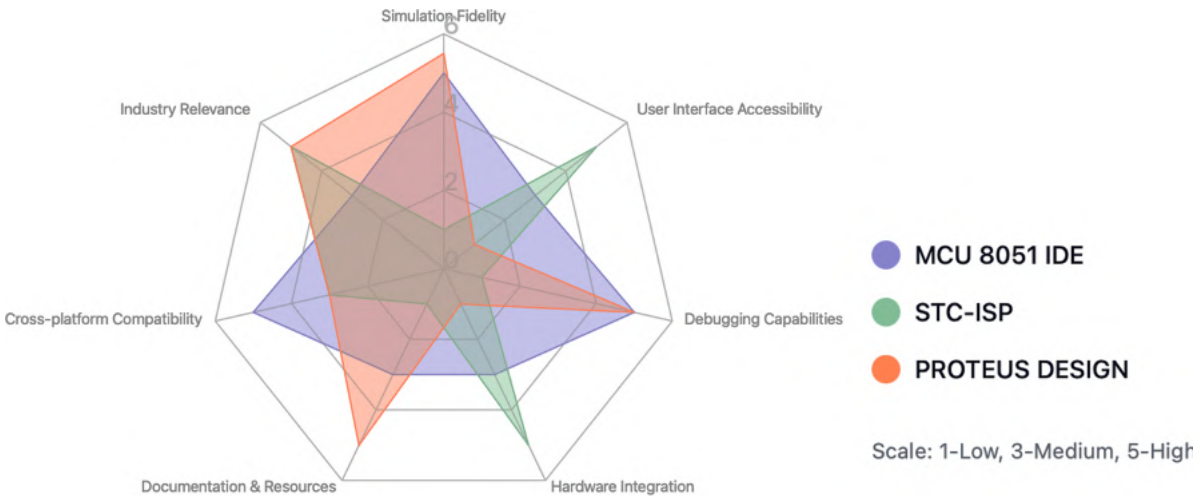

Figure 5: Criteria-based effectiveness comparison.

- For comprehensive learning covering both simulation and practical implementation, MCU 8051 IDE offers the most balanced approach;
- For courses emphasizing hardware interaction and real-world implementation, STC-ISP provides superior hardware integration;
- For detailed simulation-focused learning with strong documentation support, PROTEUS DESIGN would be most effective.

4. Experimental assessment of educational tools' effectiveness in developing engineering students' digital competences

The study employed a comparative analysis between an experimental group (26 students) utilising the new educational technologies and a control group (26 students) following traditional teaching methods.

The experimental group's curriculum incorporated: hardware-software co-design platforms; project-based learning scenarios; industry-aligned problem-solving tasks; collaborative design challenges; self-directed learning components; simulation and physical prototyping tools, authentic assessment methods. Student performance was evaluated through: standardised examinations; project assessments; digital competence rubrics; self-efficacy surveys; industry-readiness evaluations.

For a well-substantiated analysis of the effectiveness of implementing educational tools in the teaching process of the microprocessor system, a comparative study of academic performance between the experimental and control groups of students was conducted (table 3).

Table 3
Comparison of academic performance metrics.

Performance metric	Experimental group	Control group	Improvement (%)
Average score	72.87	61.94	17.65%
Pass rate	100.00%	85.00%	17.65%
Excellent rate	26.09%	18.26%	42.86%
Good rate	26.09%	22.17%	17.68%
Satisfactory rate	47.83%	52.61%	-9.09%*

Note: The lower percentage in the satisfactory rate category for the experimental group reflects a positive outcome, as more students achieved higher grades.

The experimental group demonstrated a balanced distribution across grade categories: A (excellent):

6 students (26.09%); B (very good): 2 students (8.70%); C (good): 4 students (17.39%); D (satisfactory): 6 students (26.09%); E (sufficient): 5 students (21.74%). The experimental group demonstrated substantial improvements in academic performance compared to the control group. The most notable improvement was in the proportion of students achieving excellent grades (42.86% increase), suggesting that the implemented tools were particularly effective in supporting high-level learning outcomes. The 100% pass rate in the experimental group further demonstrates the effectiveness of the approach in supporting all learners. In addition to improving academic performance, an important aspect of the research was the assessment of students' digital competence development in accordance with European standards. For an objective measurement of digital skills proficiency levels, an evaluation was conducted using a 10-point scale across various competence areas. The results of this assessment are presented in the table below, which reflects significant differences between the experimental group that studied using specialised educational tools and the control group (table 4).

Table 4
Digital competence ratings.

Competence area	Experimental group	Control group	Improvement (%)
Problem solving	8.7	7.1	22.54%
Technical proficiency	8.5	6.8	25.00%
Independent learning	8.2	6.4	28.12%
Collaboration	8.9	7.3	21.92%
Industry readiness	8.3	6.5	27.69%

All measured areas of digital competence showed significant improvement, with independent learning skills showing the most substantial gains (28.12%). This suggests that the new educational tools successfully foster self-directed learning capabilities. The high ratings for industry readiness (8.3/10) indicate that the approach effectively bridges the gap between academic learning and professional practice. The experimental implementation of innovative educational tools for microprocessor systems design yielded: significantly higher academic performance (17.65% increase in average scores); enhanced digital competence across all measured domains. This study provides compelling evidence that well-designed educational tools for microprocessor systems design can significantly enhance digital competence development among engineering students, with measurable improvements in both academic performance and industry-relevant skills.

5. Conclusions

This research demonstrates that a comprehensive approach to microprocessor systems design education, integrating specialised software tools and hardware platforms, significantly enhances digital competence development among engineering students. The comparative analysis of MCU 8051 IDE, STC-ISP, and PROTEUS DESIGN revealed distinct complementary strengths, supporting the implementation of a multi-tool learning environment that mirrors professional workflows.

The quasi-experimental study provided compelling evidence of the effectiveness of this approach, with the experimental group demonstrating marked improvements across all measured metrics. The 17.65% increase in average academic performance, combined with a 100% pass rate and 42.86% improvement in excellent grades, validates the pedagogical framework developed in this research.

Particularly significant was the development of digital competencies aligned with industry requirements. The substantial improvements in problem-solving (22.54%), technical proficiency (25%), independent learning (28.12%), collaboration (21.92%), and industry readiness (27.69%) suggest that the implemented methodology successfully bridges the gap between academic knowledge and professional practice.

Declaration on Generative AI

AI served as an assistant in research development, specifically for editing and translation purposes. All theoretical constructs, data interpretations, and conclusions were developed by researchers, ensuring that AI enhanced rather than replaced human expertise in the research process.

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Information and consulting environment of the vocational education institution: a barrier-free space

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Abstract

The study focuses on defining and substantiating the concept of the information and consulting environment of a vocational education institution (VEI), which facilitates information exchange, consultative support, and the active involvement of all participants in the educational process. Drawing on environmental, creative-developmental, and systemic-structural approaches, the research outlines the content of the VEI's information and consulting environment and the criteria for its effective organisation. Observation and SWOT analysis reveal digital and sociocultural barriers to the provision of educational services amid military events in Ukraine. By applying retrospective, comparative, systemic analysis, and modelling methods, the study develops a methodology for optimising the organisation of the VEI's information and consulting environment to ensure its inclusivity and accessibility. This environment represents a multi-component system of educational resources and technologies that enable the informatisation, digitalisation, and automation of consulting services. Its well-structured organisation supports the modernisation of the educational process and fosters inclusive engagement through the integration of informational, consultative, diagnostic, interactive, coordinating, professional development, and instructional-methodological functions. Its structure encompasses social, spatial-object, and psycho-pedagogical dimensions. The research identifies significant achievements of Ukrainian VEIs in this area while also highlighting a critical insufficiency in the systemic-structural characteristics of the existing environments. This underscores the need for a qualitative renewal of their conceptual foundations, content, organisational models, and technological solutions. The proposed methodology for organising the VEI's information and consulting environment aims to raise the quality of educational services, enhance inclusivity by integrating participants through information flows, and foster collaboration and co-creation in the institution's development.

Keywords

Ukrainian vocational education system, vocational education institution, information and consulting services, barrier-free environment of the vocational education institution, inclusive information and consulting environment

1. Introduction

The contemporary challenges in education encompass not only the enhancement of specialists' professional preparedness but also the creation of a qualitatively new environment within educational institutions. Such an environment is expected to cultivate essential attributes in future specialists, including competitiveness and readiness for sustained professional success. In turn, enterprises and society as a whole demand specialist who are independent, proactive, and responsible, capable of active engagement and effective interaction in addressing social, production, and economic challenges. The responsibility for preparing such specialists squarely rests with vocational education institutions (VEIs).

Currently, vocational education has experienced a significant decline in prestige, which is attributed to a complex set of factors. These include demographic decline both in Ukraine and internationally, a rise in labour migration, elevated social expectations among young people regarding employment, a misalignment between labour market demands and the quality of workforce training, deficiencies

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in career guidance systems rooted in outdated approaches, the accessibility of education abroad, the growing influence of social media on career decisions and lifestyle choices, transformations in educational organisation driven by the COVID-19 pandemic, and, unquestionably, the ongoing martial state in Ukraine [1, 2, 3].

Against this backdrop, it is important to emphasise that the development of an inclusive and barrier-free information and consulting environment within vocational education institutions is of critical importance for ensuring the delivery of high-quality educational services. Among the pivotal factors are the readiness of both staff and learners to engage in consulting activities, leveraging modern ICT tools, multichannel online consulting formats, and fostering creative, subject-to-subject interactions [4]. The digital space plays a pivotal role in this transformation, as institutions are increasingly adopting electronic educational platforms and 3D modelling technologies to enrich the learning environment [5]. Building an inclusive environment requires architectural, informational, and social accessibility, alongside the provision of an adequate material and technical base [6]. Effective implementation in this regard entails comprehensive teacher training, the establishment of inclusive clubs, and the promotion of student-led initiatives. At the same time, researchers underscore the existence of a gap between the opportunities offered by educational institutions and the extent to which students can fully capitalise on them, thereby highlighting the importance of fostering active learner participation in inclusive education [7].

In view of these considerations, the process demands a fundamental restructuring of consulting services, grounded in a person-centred approach, alongside the transformation of methods for working with information and clients. It also necessitates the reorganisation of data collection, exchange, storage, and processing channels through the deployment of ICT and AI technologies.

2. Purpose

The study is dedicated to identifying and substantiating the concept of an information and consulting environment of a VEI, within which information exchange, consultative support, and maximum inclusion of subjects in the educational process become possible.

3. Design/Methodology/Approach

Based on environmental, creative-developmental, and systemic-structural approaches, the content of a VEI's information and consulting environment, as well as the criteria of its organization, are presented. Through results from observation and SWOT analysis, digital and sociocultural barriers to providing educational services during military events in Ukraine are identified. Employing methods of retrospective, comparative, systemic analysis, and modelling, a methodology is designed to ensure an optimal level of organization of a VEI's information and consulting environment, its maximum inclusiveness and accessibility.

4. Theoretical background

The research concept is based on understanding the *environment* as a system of conditions created in a specific space where the subject's activities occur, and the *environmental approach* is defined as a strategy founded on managing the process of personal development through the creation of a specific environment [8].

Given this, the modern *VEI's educational environment* should be considered a material-technological, social, and physical-spatial environment characterized by intelligent design, accessibility, innovation, business orientation, openness, inclusiveness, and value orientation, which collectively contribute to acquiring lifelong vocational education competencies regardless of geographical, gender, racial, or cultural affiliation [9].

Considering the content of the core categories, the VEI's information and consulting environment is defined as a relevant part of the space for the information society, inside which barrier-free, maximally inclusive information exchange and consulting support for the subjects of the educational process and other interested parties through computer-oriented technologies become possible [10, 11, 12]. This environment is associated with the VEI's information educational environment and embodies the tools and methods of providing consulting services and information exchange for educational purposes. Within its framework, consulting services are supplied to teaching staff, students, administrative and service structures, parents, and social partners to improve the quality of educational provisions [13, 4].

Integrating the qualities of both types of educational spaces (educational consulting and informational educational ones), the information and consulting environment, using ICT and computer-oriented pedagogical technologies, is capable of enhancing the advantages and compensating for some of the shortcomings of each [14, 15]. Its *functions* combine informational, consulting, diagnostic, interactive, coordinating, professional-developmental ones, and functions of pedagogical and educational-methodological support for all subjects in the educational process and stakeholders [16, 17, 18].

It was established in our earlier research that the information and consulting environment is a multi-component complex of educational resources and technologies that provide informatization and automation of consulting services. For this goal, the environment creates opportunities to implement a range of computer-oriented pedagogical technologies and technologies that ensure an appropriate level of consulting services [19, 20, 21, 22, 23, 24, 15] (figure 1).

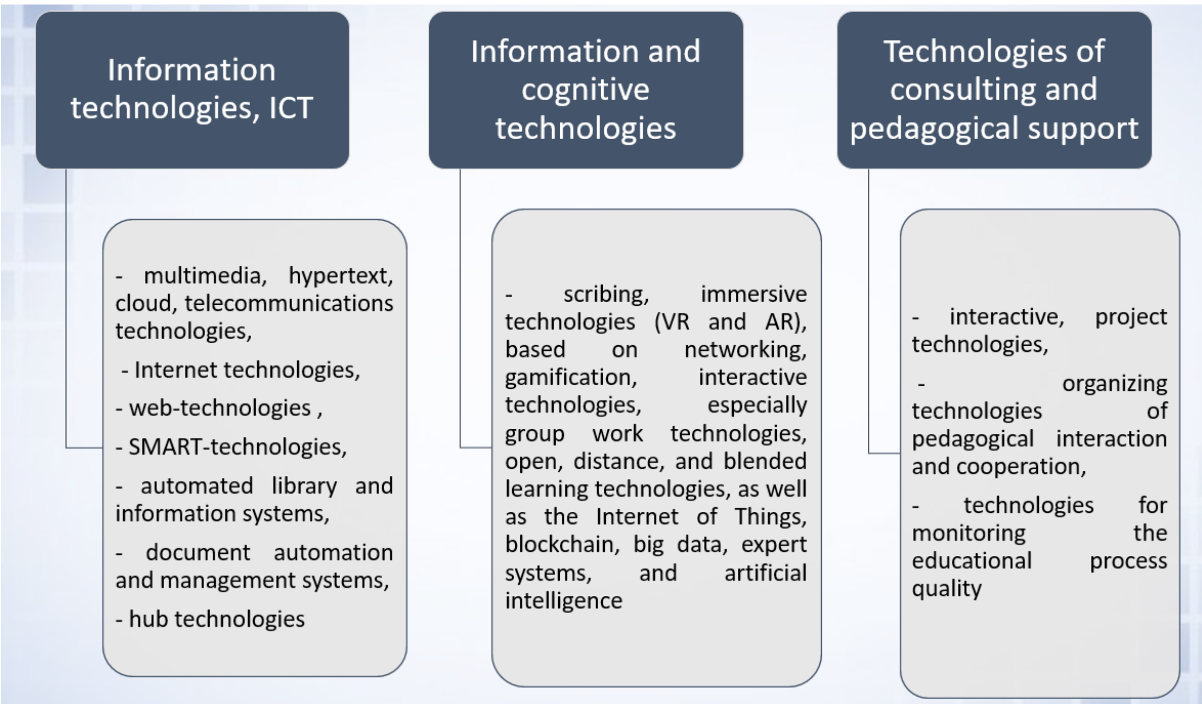

Figure 1: Technologies of the VEI's information and consulting environment.

Most of the mentioned technologies possess didactic properties such as *barrier-free access to information and data* from any geographical area, from any digital device, in a 24/7 format; *personalization* (unlimited opportunities for individualization according to the needs and characteristics of learners); *interactivity* (ensuring multi-subjectivity in the process of educational interaction); *multimedia* (comprehensive involvement of various channels of information perception and ways of manipulating it); *hypertextuality* (free navigation through the text, use of cross-references, reference nature of the information, etc.); *subculturality*, etc. [9, 25, 12].

The information and consulting environment can be distinguished into several components. It consists of the *social component* encompassing the participants of the environment and its socio-cultural surroundings, the *spatial-object component* defining its topographical design, and the *psychological and* *pedagogical component* covering methodological support for the implementation of the environmental goals (figure 2).

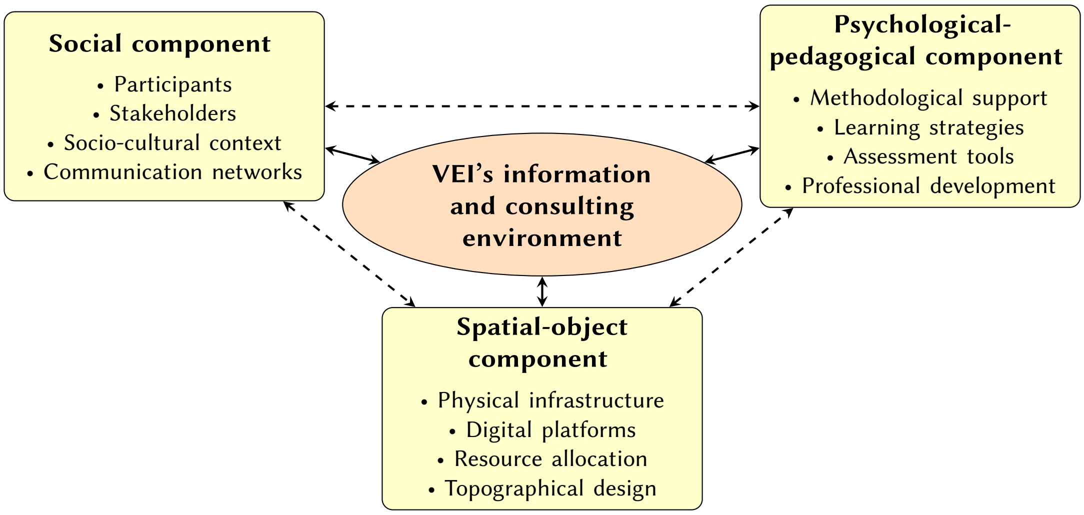

Figure 2: Content and structure of the VEI's information and consulting environment.

The *criteria* reflecting the inclusivity of the VEI's information and consulting environment in the context of removing digital and socio-cultural barriers for its users cover the system-structural criterion, the criterion of readiness of teaching staff and students for consulting activities using the environment's tools, and the level of satisfaction of the subjects of the educational process with the information-consulting services of the environment. The corresponding indicators are presented in figure 3.

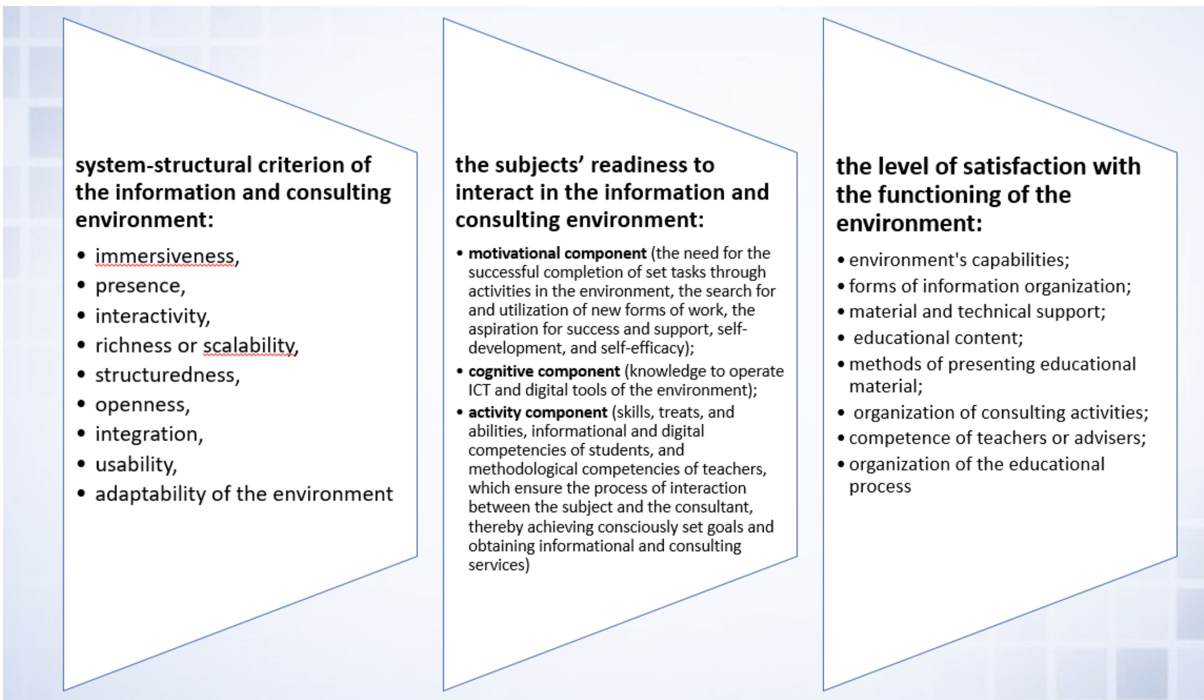

Figure 3: Criteria for the inclusivity of the VEI's information and consulting environment [26, 27, 12].

Based on the brightness of their manifestation, the pedagogical monitoring of the state of functioning of the environment becomes enabled according to the unsatisfactory, critical, sufficient and high levels indicators.

These theoretical generalisations provide the foundation for designing a model for the organisation of the information and consulting environment within vocational education institutions, alongside a system of pedagogical measures aimed at ensuring barrier-free and inclusive access to consulting services for all educational participants and stakeholders.

5. Results

The study of the state of the problem of organising the information and consulting environment in VEIs across Ukraine was carried out over the period 2022–2024. Throughout these years, it engaged a total of 400 students from Kryvyi Rih Applied College of Trade and Hotel and Restaurant Business, the State Educational Establishment “Interregional Higher Professional School of Polygraphy and Information Technologies” (Dnipro), the Private Institution “Centre for Vocational Education and Training” (Kryvyi Rih), the Subdivision “Lviv Professional College of Food and Processing Industry, National University of Food Technologies”, as well as 200 teachers, including 60 members of administrative staff.

The first stage of the empirical research involved conducting a SWOT analysis of the obtained results, which identified the opportunities and threats, as well as the strengths and weaknesses present in this area of VEIs’ activity [12]. This analysis recorded the undeniable achievements of vocational education institutions in establishing modern, functional, and dynamic information and consulting environments that meet contemporary requirements and demonstrate considerable potential (as shown in Table 1).

Table 1
SWOT analysis of the functioning of the VEI’s information and consulting environment.

Opportunities	**Threats**
– Raising the institution’s ranking. – Enhancing the quality of educational services. – Improving information culture and awareness among participants and stakeholders. – Development of innovative consulting structures (techno park, hub, automated systems). – Broad opportunities for training and development within a unified environment. – Automation and modernisation of education and consulting services.	– Risk of ranking decline due to insufficient resource provision. – Loss of traditional forms of consultation. – Decrease in inclusivity indicators. – Growth of digital barriers. – Limited development of professional skills and practical training. – Ineffective management of information and consulting flows.
Strengths	**Weaknesses**
– 24/7 consultative support. – Readiness to use ICT across institutional activities. – Accessible communication for all participants. – High stakeholder and expert engagement. – Implementation of distance, blended, and mobile learning formats. – Reduced costs for educational and consulting services.	– Dependence on internet and hardware/software infrastructure. – Reduced live communication. – Additional costs for maintaining the information environment remotely. – Decline in students’ independent learning quality. – Challenges in monitoring the professional development of students and staff.

Based on the results of the SWOT analysis, a “probability-consequences of threats” matrix was constructed (table 2) [12].

The analysis of the obtained data highlighted the need for a qualitative update of the conceptual, content, organizational, and technical-technological aspects of the functioning of the barrier-free information and consulting environment in VEI (figure 4).

Based on the analysis of primary sources and empirical data, conditions have been identified. They facilitate overcoming difficulties and resolving contradictions in the studied scientific area, ensuring the optimal organization and effective functioning of the VEI’s information and consulting environment. The creation of resource, methodological, technical, and organizational terms, collectively aimed at developing all subjects of the educational process – students, educators, administration, parents, and social partners – secures their effectiveness through the organizational and managerial activities of

Table 2
Matrix of probability – consequences of threats in the organization of the VEI's information and consulting environment

Probability	Consequences of threats		
	Destructive	**Severe**	**Minor**
High	Non-functioning environment due to the lack of energy resources	Transition of highly qualified staff/advisers to other institutions	Low readiness level of participants for information and consulting activities
Medium	Decrease in inclusivity indicators	Lack of funding to support the environment's resources	The presence of competitors with better-organized (functioning) environments
Low	Increase in digital and sociocultural barriers	The absence of separate information and consulting services in the institution	Inadequate motivation of participants in information and consulting activities

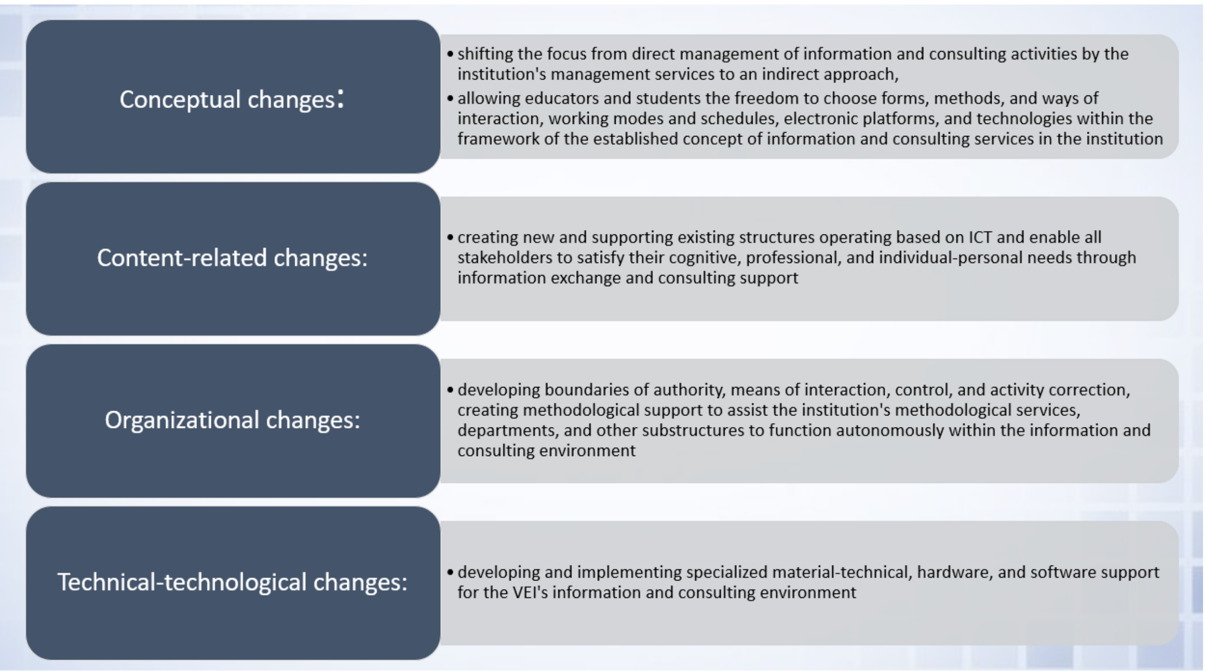

Figure 4: Aspects of comprehensive renewal of the information and consulting environment in VEI.

the administration and educators. This facilitates the formation of an innovative personality in future specialists within a barrier-free inclusive educational environment.

The integration of the above factors allows for the formulation of a comprehensive set of necessary and sufficient pedagogical terms as circumstances under which the components of the VEI's information and consulting environment are in the best possible interconnection. This creates an atmosphere of fruitful collaboration and provides productive teaching, effective management of the educational process, and the provision of quality educational services (figure 5).

To provide direction in organizing an inclusive and barrier-free information and consulting environment in VEI, a special methodology has been developed. The modelling of this methodology was grounded on scientific concepts regarding its goals, objectives, content, stages, forms, and methods, as well as on social expectations concerning its results in addressing the main tasks of the institution; it structured formative influences into the *target, organizational and content, and evaluate and resultative blocks.*

The *target block* reveals the core principles of organising the information and consulting environment, detailing its goals, objectives, as well as the approaches and principles that underpin the methodology for its implementation in a vocational education institution. The *organizational and content block* of

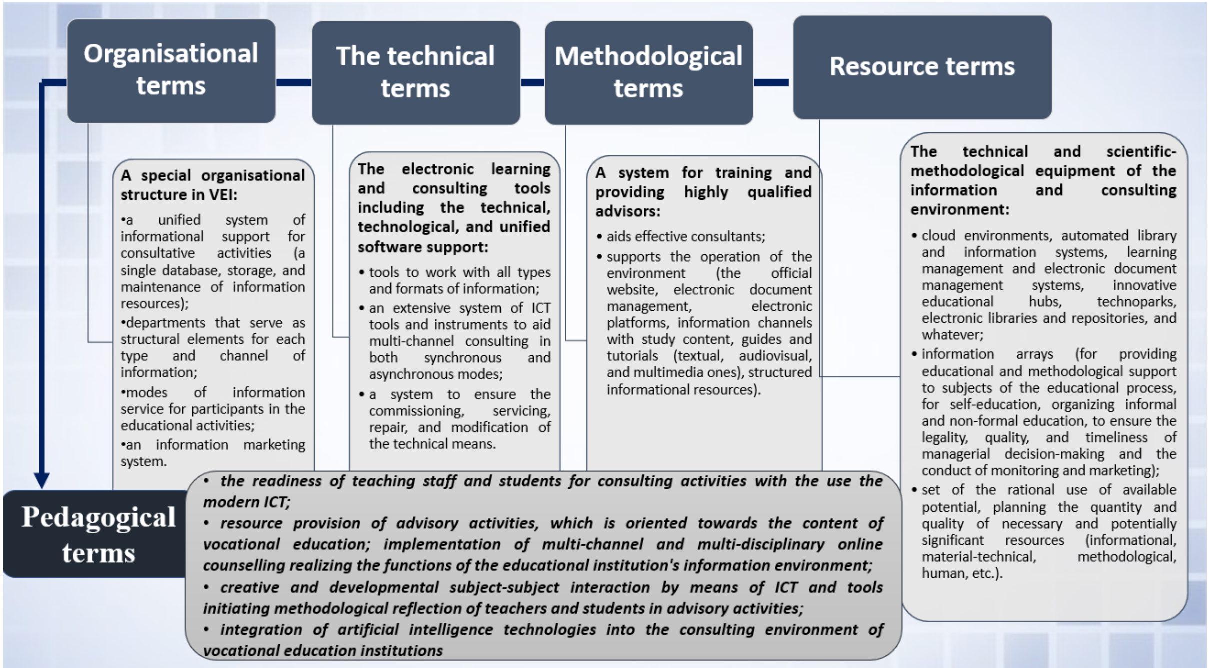

Figure 5: The system of terms for the functioning of the VEI's information and consulting environment [12].

the model specifies the structure, methods, formats, and technologies for setting up the information and consulting environment in the vocational education institution, while also coordinating the logical sequence and phases of this process, namely: organisational-methodical, activity-productive, and control-prognostic ones. The *evaluate and resultative block* outlines the criteria, levels, and diagnostic tools that serve as indicators of the effectiveness of organising the information and consulting environment in the vocational education institution. The intended *outcome* of applying the methodology is to ensure the predominance of sufficient and high levels of organisation of the information and consulting environment, thereby enabling the full realisation of its key functions within the vocational education institution (figure 6).

To ensure the effective implementation of the developed methodology, it is essential to purposefully establish the identified pedagogical terms. It should be emphasised that the optimal organisation of the information and consulting environment in a VEI is facilitated by the creation of these terms.

Specifically, an *adequate level of readiness among the teaching staff and students for consulting activities with the use the modern ICT* allows for the psychological, cognitive, and activity-based training of all subjects of the educational process for utilizing the opportunities provided by the such environment in their personal and professional development.

In order to provide direction in fostering the readiness of the administration, teaching staff, and learners of the educational institution for effective engagement within the information and consulting environment of the vocational education institution, we have developed and piloted a series of four seminars entitled *"The System of Consulting Services in the Vocational Education Institution"* (table 3).

Each session involved the active engagement of both teaching staff and learners in discussing the means of organising the information and consulting environment, the methods and techniques for its implementation, and the exchange of ideas and experiences in the use of digital technologies within the educational institution and the preparation of qualified specialists. Following each session and upon completion of the seminar series, rapid surveys and discussions were conducted with both students and teachers, using Google Forms and the communication tool Zoom. The purpose was to adjust the content and formats of methodological work, to assess participants' readiness, and to emphasise the necessity of developing consulting services within the educational sector of Ukraine, highlighting the role of innovative technologies and AI as powerful drivers in building inclusive and barrier-free educational environment.

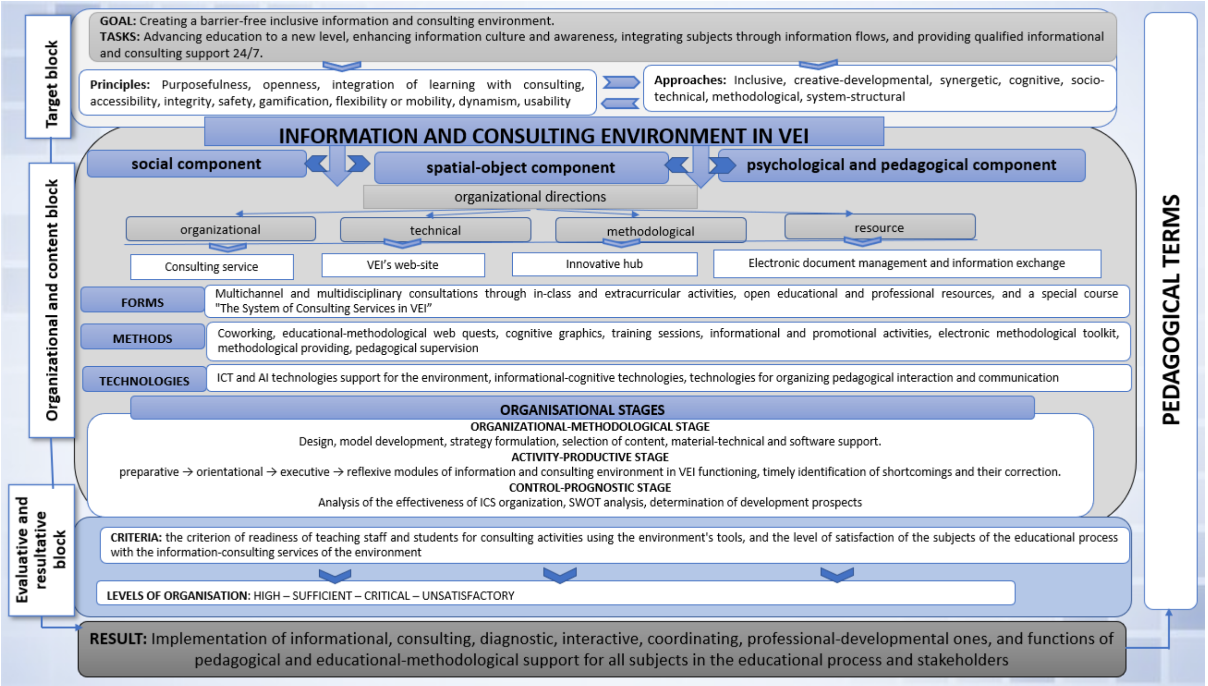

Figure 6: Model of the methodology for organizing a barrier-free inclusive VEI's information and consulting environment.

The next pedagogical term implied *the establishment of resource provision for consulting activities, tailored to the content of vocational education*. This involved the renewal and enhancement of the institution's technical infrastructure, human resources, and educational-methodological support, aimed at strengthening its information and consulting capacity by upgrading the institutional website, training and involving qualified consultants, incorporating open educational resources, employing cloud technologies, leveraging the opportunities offered by MOOC platforms, and integrating artificial intelligence technologies into consulting services.

Our approach was based on the premise that providing advisory activities focused on the content of vocational education enables the use of technical, human, and educational-methodological resources to support the educational process, oriented towards the requirements of the Professional Education Standard and the anticipatory development of the professional field.

Within the framework of the experiment on organising the information and consulting environment of the vocational education institution, and in collaboration with and with the support of the methodological and human resources departments of vocational and professional pre-tertiary education institutions, the following resources were analysed and further developed, with a special focus on fostering inclusivity and barrier-free access to educational and consulting services in the context of martial law. These efforts specifically addressed the enhancement of the following resource components:

- *Technical resources* (the physical component of the environment): a comprehensive catalogue and database were created, priorities and critical factors for their utilisation were identified, a development plan was formulated and aligned with the capacities of partner institutions, employers, and cloud services providers, with particular attention to the integration of AI-driven systems and digital tools to support blended and distance learning and consulting formats.
- *Human resources* (the intellectual component of the environment): training was provided for consultants and supervisors of teaching staff; guest consultative events were introduced; forward-looking professional development plans were developed, along with a model for preparing learners and students to engage effectively with consulting services, including the use of AI tools and innovative educational technologies.
- *Educational and methodological resources* (the informational component of the environment): an

Table 3
Structure of the seminar series "The System of Consulting Services in the Vocational Education Institution" (12 hours).

№	Seminar topic	Key issues addressed	ICT tools utilised
1	The system of consulting services in the vocational education institution (2 hours)	Conceptual foundations of "consulting": definition, distinctive features, and functions. Objectives of consulting activities in education. Functions of pedagogical consulting.	Institutional websites, methodological hub, coworking spaces, electronic methodological repository, online consulting tools.
2	The educational institution website as an essential component of the information and consulting environment (2 hours)	Development of criteria for an effective institutional website. The website as a tool for delivering consulting services. Evaluation of top-performing institutional websites. Content management and resource provision.	Institutional website incorporating: electronic library, digital gradebook, methodological and instructional resources, thematic blogs and teacher websites.
3	Innovation hubs as an effective component of educational modernisation (2 hours)	Goals and functions of the educational hub. Identification of key outcomes of innovation hubs within educational institutions.	Internet servers, e-textbooks, reference materials, encyclopaedias, educational videos, multimedia resources, testing tools. Sector-specific internet servers for individual and group learning and knowledge exchange. Google Workspace, "IT HUB coworking", NOTBOX hub.
4	Electronic document management and its implementation (2 hours)	Stages of introducing electronic document management (EDM) in the institution. Use of electronic (digital) gradebooks. Prospects for EDM integration within educational institutions.	Model of EDM implementation, use of digital gradebooks, electronic archiving, and data exchange through EDM systems.
5	E-learning tools (2 hours)	Distance learning technologies. Development of digital educational content. Design of cognitive visualisations. Production of video tutorials.	Personal teacher websites (blogs), open educational resources, methods for creating multimedia methodological guides.
6	Integration of AI into the consulting services system (2 hours)	Opportunities for integrating AI into consulting activities. Personalisation of consulting services through AI. AI tools for analysing information requests and automating responses. Ethical considerations in AI use.	AI-based platforms and tools for educational consulting, chatbots, AI-driven data analysis systems, adaptive learning technologies.

electronic methodological repository, electronic gradebook, learning management systems, content management systems, thematic pages, social media posts, methodological blogs, workshops, open educational resources, educational content, video tutorials, guidelines, and algorithms were created and systematised, supplemented by AI-based tools and interactive platforms designed to enhance blended and distance consulting services.

The implementation of multichannel and multidisciplinary online consulting, which realizes the functions of the educational institution's information environment, permits the fulfilment of the potential of various types of consultations, increasing the website traffic of the institution due to the relevance of its resources, and ensuring the significance of the accessible tools of the website (LMS, LCS, messengers, blogs, mobile applications, educational institution web pages, electronic document management and its structural units, electronic library, etc.).

In this context, *the creative-developmental subject-subject interaction via ICT tools, which initiates methodological reflection among teachers and students in advisory activities*, concentrates on organizing an environment where not only information exchange occurs but also the creative application of all resources, their development by the transfer of ideas and project activities involving all subjects engaged in the information and consulting environment.

This requirement was met by establishing an Innovation Hub within the educational institution. The principal technologies utilised in the operation of the Innovation Hub include coworking (collaborative creative and cognitive activity within a purpose-designed environment), information and cloud technologies, AI, and educational-methodological web quests. The creation of the Innovation Hub began with the collection and systematisation of electronic learning materials and resources to support the educational process. Special emphasis was placed on developing electronic libraries and educational resources, structured in accordance with the needs of users – both consultants and recipients of information and consulting services.

One of the crucial areas of activity within the Innovation Hub is the development of cloud storage systems to centralise sector-specific informational and educational resources, including electronic textbooks and reference materials, encyclopaedias, video tutorials, multimedia tools, testing resources, and other materials selected to support both individual and group forms of learning and consulting. Access routes to these servers were provided on the website of the educational institution.

In this study, the Innovation Hub is viewed not merely as a modern version of an electronic methodological repository, but rather as a cultural environment that enables qualified pedagogical guidance and supervision of teachers' professional development and the educational and professional activities of learners and students. This complex objective was achieved through the implementation of specific initiatives within the framework of the Innovation Hub (table 4).

Table 4
Cycle schedule of activities of the Innovation Educational Hub.

For managers	For teachers	For students
Methodological consultation: *Opportunities of the institution's Innovation Hub.*	Methodological events: *Integration of ICT in the management process.*	Methodological consultation: *Opportunities of the institution's Innovation Hub.*
Reporting and analytical methodological meeting.	Webinar: *Professional competence of the teacher.*	Virtual school for preparation for External Independent Testing (EIT).
Methodological events: *Integration of ICT in the management process.*	Web consultation with guest lecturers.	Virtual school for preparation for PISA assessment.
Webinar: *Professional competence of the teacher.*	Scientific and practical seminar: *Effectiveness of the institution's methodological work.*	Methodological support.
Scientific and practical seminar: *Effectiveness of the institution's methodological work.*	Methodological events: *Certification of teaching staff.*	Ongoing master classes.
Web consultation with guest lecturers.	Methodological support.	Methodological events: *Library in the context of distance learning.*
	Multichannel and multidisciplinary consulting.	Consulting support.
		Multichannel and multidisciplinary consulting.

An essential pedagogical term was the *integration of artificial intelligence technologies into the consulting environment of vocational education institutions*, with a focus on expanding access to consulting services and ensuring their continuity under the constraints of martial law. Particular attention was given to the deployment of AI-powered chatbots, such as ChatGPT and other specialised consulting bots integrated into institutional websites and learning management systems. These tools provided automated, round-the-clock support to both teachers and learners, offering assistance with navigating educational platforms, accessing methodological resources, and resolving routine academic and organisational inquiries. For example, chatbots were used to guide students through course registration processes, explain assessment criteria, and direct them to appropriate support services. The application of these technologies reduced the workload on human consultants, increased the responsiveness of the consulting system, and maintained inclusivity by ensuring continuous support regardless of users' location or individual circumstances. The integration of such solutions has strengthened the capacity of vocational education institutions to deliver high-quality consulting services in both blended and distance learning formats while supporting the creation of a barrier-free educational environment [28, 25].

The quantitative, qualitative, and statistical analyses conducted upon completion of the methodology's piloting revealed a positive trend in the levels of organisation of the information and consulting environment in vocational education institutions (table 5).

Table 5
Summarized dynamics of the levels of organization of the VEIs' information and consulting environment in vocational education institutions for the experiment results.

Criteria	Experimental group	Control group
The subjects' readiness to interact in the information and consulting environment:	+32%*	+8%*
motivational component	+34%	+7%
cognitive component	+20%	+8%
activity component	+30%	+6%
The level of satisfaction with the functioning of the environment	+36.7%	+11.4%
System-structural criterion	Critical → High Level**	Critical → Sufficient Level**

*$\rho < 0.001$ by Pearson's chi-squared test
**$\rho < 0.01$ by Student's t-test

Thus, the findings of the conducted analyses, supported by the data presented in table 5, confirm the effectiveness of the developed methodological approach and the relevance of the identified pedagogical terms. The positive dynamics observed in the levels of organisation of the information and consulting environment demonstrate the potential of the proposed solutions for improving the quality, accessibility, and inclusivity of consulting services in vocational education institutions. These outcomes provide a solid foundation for formulating general conclusions and determining further directions for research and practical implementation.

6. Conclusions

The introduction of a unified information and consulting environment in VEIs has shown significant potential in addressing current educational challenges. The comprehensive methodology developed and tested in 2022-2024 focuses on creating an inclusive, barrier-free environment that supports both personal and professional development for all participants in the educational process. This environment utilizes modern ICT tools, which facilitate the seamless exchange of information and consulting support.

The SWOT analysis conducted revealed key strengths, including the availability of consultative support 24/7 and the integration of ICT in educational activities. However, challenges such as dependence on internet infrastructure and the risk of minimizing "live" interaction were also identified. The findings underscore the importance of resource, methodological, technical, and organizational terms in supporting the optimal functioning of the information and consulting environment.

Quantitative and qualitative analyses post-experiment indicated positive changes in the organization of these environments within VEIs. Specifically, there was a notable improvement in the readiness of educators and students to engage in consulting activities, as well as increased satisfaction with the environment's functionality. The development of innovative consulting structures, such as technoparks and hubs, and the effective use of online and multidisciplinary consultations, integrative of AI technologies were critical in enhancing the educational process.

The scientific-theoretical significance lies in the developed resource provision for consultative activities; ways for implementing multi-channel and multi-disciplinary online consulting; procedures for creative-developmental subject-to-subject interaction via digital technologies. The practical significance of the results occupies in creating tools for direct and indirect pedagogical management of the process of gradually involving teaching staff and students in information and consulting activities in the form of methodological events and networking; the concept of an innovative educational hub, the structure of the institution's system of electronic document management and information exchange.

In summary, the effective organization of the information and consulting environment in VEIs requires a strategic approach that integrates ICT and emphasizes inclusivity and accessibility. This approach not only enhances the quality of educational services but also aligns with the evolving demands of the digital economy and professional standards. The continued development and implementation of such environments are crucial for fostering innovative and competent professionals equipped to meet future societal needs which is particularly important during the wartime and post-war recovery period in Ukraine.

6.1. Limitations

The study was conducted based on two VEIs and two institutions of higher vocational education in Ukraine. Its results and main provisions cannot be uncritically applied to the functioning of HEI. Furthermore, considering the continuous digital transformation of all life spheres, it is necessary to periodically review specific provisions of this research in the context of the latest technological trends and changes in the organisation of educational systems.

Declaration on Generative AI

During the preparation of this article, artificial intelligence technologies were used solely as auxiliary tools to enhance the quality of academic writing, to ensure linguistic accuracy, and to optimise the structure of the text. The authors retained full control over the content, structure, and scientific argumentation of the article. AI-assisted tools were applied exclusively for language editing, formatting suggestions, and checking stylistic consistency, without generating original research findings or influencing the scientific conclusions presented in the work. All conceptual development, data analysis, and interpretation of results were conducted independently by the authors.

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Cloud technologies in the educational process: development and implementation of a suite of online services for the professional activities of primary school teachers

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Abstract

The article explores the integration of cloud-based ICT, particularly online services, into the professional activities of primary school teachers. Grounded in systemic and competency-based approaches, an open suite of online services has been designed to support face-to-face, distance, and blended learning formats, reflecting the preferences of primary educators as identified through a longitudinal study. In alignment with the content and demands of professional teaching practice, particularly in fulfilling Job Function A under contemporary educational conditions, this suite comprises a structured system of services that enables teachers to both utilize ready-made digital learning tools and develop their own ICT-based instructional resources. Group I – services for creating interactive educational content; Group II – services for organizing and conducting an online lesson; Group III – services for creating a virtual classroom and an electronic journal. Based on the fact that this complex is open, a system of requirements for the selection of online services is presented. The effectiveness of the developed complex was experimentally proved during a pedagogical experiment on the basis of the Izmail State Humanitarian University. As a result of mastering the developed complex, students majoring in Primary Education demonstrated creative projects for organizing a mathematics lesson in primary school with the possible use of a set of online services

Keywords

ICT, a set of online services, primary school teacher, professional activity,

1. Introduction

Since 2019, in response to the COVID-19 pandemic, educational institutions in Ukraine have transitioned to a distance learning format [1, 2, 3]. In the post-pandemic period, beginning in February 2022, a substantial proportion of general secondary education institutions (GSEIs) in Ukraine have continued to operate in distance or blended learning modes [4, 5] due to the ongoing armed aggression of the Russian Federation [6, 7]. The continuity of the educational process under crisis conditions has been made possible through the rapid advancement and integration of cloud technologies within the educational ecosystem. Papadakis et al. [8] emphasize the importance of cloud technologies for open education, which provides access to educational resources and platforms regardless of the location of participants in the educational process.

Cloud technologies are the foundation for creating modern educational platforms that provide access to educational resources, tools and services regardless of the user's location [9, 10, 11, 12, 13]. This allows you to organize both distance and blended learning, increasing the flexibility and adaptability of the educational process [14]. In particular, cloud services (Google Workspace for Education, Microsoft

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Teams and others) provide teachers with the opportunity to create, store and distribute educational materials from any device with access to the Internet, which significantly increases flexibility in planning the educational process and organizing distance or blended learning.

Cloud platforms facilitate synchronous collaborative interaction between teachers and students in real time, enhancing interactivity, enabling immediate feedback, and improving the overall efficiency of the educational process. Furthermore, cloud technologies support the systematic collection and analytical processing of data on students' academic performance, thereby enabling educators to tailor instructional approaches and implement personalized learning trajectories for each student [8, 15].

The use of cloud platforms in primary education allows teachers and students to work with interactive materials, virtual laboratories, and collaborate on projects in real time [15]. The implementation of cloud services provides teachers with tools for developing interactive tasks, test materials, presentations and multimedia content (using resources such as Kahoot!, Quizlet, Padlet, Canva, etc.), which positively affects the motivation of students and the quality of learning. The synergy of cloud technologies and augmented reality (AR) opens up new opportunities for visualizing complex concepts, conducting simulation experiments and increasing student motivation [16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27]. Papadakis et al. [15] show that such integration significantly expands the capabilities of the educational environment and contributes to the development of students' creative potential.

In the context of crisis challenges faced by Ukrainian education, cloud technologies demonstrate their potential as an effective means of ensuring the continuity of the educational process. Cloud technologies are an integral part of information and communication technologies (ICT), as they provide access to modern digital educational resources, tools and services that significantly expand the didactic potential of the educational process and increase its effectiveness.

Research by Ukrainian scholars [28, 29, 30, 31, 32] and international researchers [33, 34, 35, 36, 37, 38] demonstrates the widespread implementation of ICT in professional teaching practice.

Bulgarian researchers Terzieva et al. [39] documented significant changes in ICT usage in Bulgarian schools over the past decade, noting diverse digital tools including interactive whiteboards, computers, educational games, and augmented and virtual reality technologies .

A comprehensive survey by Terzieva et al. [35] involving 1,600 teachers and approximately 7,000 students revealed:

1. Most teachers preferred applying ICT for instructional activities, exercises, supplementary material research, and project work, while considering ICT less suitable for assessment and motivation.
2. Teachers primarily created presentations, instructional videos, electronic textbooks, specialized software, and supplementary electronic resources. They experienced difficulties with electronic testing, educational games, virtual laboratories, and simulations.
3. Regarding self-assessment of ICT competence, 33% rated themselves "excellent," 27% "very good," 20% "good," 13% "insufficient," and 7% reported no competence.

Teachers attributed low ICT competence to insufficient appropriate ICT courses, noting that available training lacked practical application. A survey of 192 primary school teachers in Jordan indicates a need for knowledge on integrating digital technologies into teaching practices and engaging children in ICT-based activities [40]. Slovak researchers Záhorec et al. [37] identified comparable issues, finding that most accredited courses focused on basic or advanced technical skills rather than pedagogical application. A similar situation was observed in the Czech Republic, with researchers concluding that teachers require methodological rather than technological assistance in ICT implementation, including guidelines and specific examples of ICT application in particular subjects.

During the COVID-19 pandemic, significant challenges were identified in the implementation of distance learning precisely due to the insufficient level of digital competence of teachers [41]. Teachers used various technological tools to continue teaching students, but it turned out that not all of them had the proper training to conduct online classes. In fact, the lack of digital literacy prevented many teachers from continuing their work without the support of colleagues [42]. The main challenges included: adapting teaching materials, technical access restrictions, and increasing workload [43]. The study and analysis of research by Ukrainian and foreign scholars on the state of readiness of primary school teachers to use ICT in their professional activities [44] have shown the need to develop teachers' ICT competence.

A study by Spanish scholars Paños-Castro et al. [45] revealed an insufficient level of training of primary school teachers to use ICT during the pandemic, despite the presence of appropriate educational policies. Most respondents indicated that they had mastered ICT skills independently and expressed interest in continuous learning programs using Google Classroom, Google Sites, Google Meet and other services.

At the same time, Portuguese researchers Henriques et al. [46] found more positive dynamics – 67.7% of primary and secondary school teachers surveyed – as of 2021 already had adequate training in the use of digital resources and learning environments.

The insufficient level of digital skills among teachers does not create conditions for the effective use of cloud technologies in teaching. According to the results of international studies, in particular Papadakis et al. [15], the combination of cloud platforms with innovative tools, such as augmented reality, allows not only to expand access to quality education, but also to increase the efficiency of teaching through interactivity and collaboration. This is especially important for Ukraine, where cloud services can compensate for the limited material and technical base and facilitate the implementation of modern pedagogical approaches [14].

Augmented reality technologies can use cloud services to expand their capabilities. Brazilian researchers Lotthammer et al. [36] concluded that augmented reality on tablets in first-grade classrooms enhanced students' focus on learning material, facilitated effective assimilation, and positively influenced children's motivation for discovery.

Spanish researchers Villena Taranilla et al. [34] confirmed the potential of virtual reality in primary education as an emerging educational technology offering immersive learning, interactivity, creativity, and meaningful learning engagement. Their studies demonstrated statistically significant differences in motivation and academic performance favoring students taught using virtual reality.

Similar results were obtained in studies examining augmented reality in primary mathematics education using HP Reveal to enhance learning material perception. However, augmented reality implementation must be justified and appropriately limited to prevent cognitive overload in primary school students [47].

It should be noted that Li's [48] analysis of 1366 publications on the use of ICT in education indicates a conservative approach to the study of tools, with limited coverage of emerging ICTs (e.g. VR or AI), focusing mostly on traditional tools, while emerging or immersive technologies [49] remain largely unexplored. This study provides insight into the areas of study of ICT in education, with general issues of ICT use prevailing (62%). The author concluded that there is insufficient focus on specific educational content, tools and scenarios for ICT use in the classroom.

According to Li [48] on the training of teachers to use ICT in the process of teaching students, despite the urgent need, from 2009 to 2024 only 13% of studies were devoted to this issue, although 34% of studies directly emphasize the need to develop curricula for teachers. This indicates that the practical use of ICT in the teaching process, although mentioned, is not the central theme of most studies.

Despite the wide international representation in the analytical review of Li [48] (47 countries), studies are dominated by Turkey and the USA, while Eastern European countries are practically not represented [48]. Our attempts to analyze publications on the use of ICT by teachers in the process of teaching students also indicate their small number, which emphasizes the need to study the use of ICT in the teaching process specifically in this region, in particular in Ukraine.

In conclusion, international research demonstrates that teachers understand the importance of ICT integration in education but require professional support to enhance their ICT competence, particularly regarding methodological implementation strategies rather than purely technical skills. Based on the studies of Bulgarian [39, 35], Slovak [37], Czech [50], [38], Romanian [33] and Ukrainian [51, 52, 44] researchers, it was found that teachers need help in using ICT not only in using hardware, but also in practice-oriented training on the material of individual subjects with specific samples professional activity. Therefore, there is a need to familiarize teachers with services that help organize learning in face-to-face, distance and blended forms, namely, to create a virtual classroom, an electronic journal, interactive learning content, including virtual whiteboards, as well as services for conducting online lessons, and thus with digital resources that will greatly facilitate the organization of face-to-face, distance and blended learning.

Research purpose: To theoretically substantiate and experimentally verify the effectiveness of using a complex of online services in the professional activities of primary school teachers for organizing face-to-face, distance, and blended learning.

Research objectives:

1. To analyze the readiness of teachers to use ICT in their professional activities before and after the COVID-19 pandemic.
2. To investigate the dynamics of usage and self-assessment of ICT competence levels among primary school teachers.
3. To determine the criteria for selecting online services for organizing various forms of learning in primary school.
4. To develop and scientifically substantiate a complex of online services for the professional activities of primary school teachers.
5. To experimentally verify the effectiveness of the developed complex of online services in the process of training future primary school teachers.
6. To develop methodological recommendations for implementing the complex of online services in the professional activities of primary school teachers, taking into account their needs for methodological support.

Taking into account the already described needs of the educational process, the components of this complex of online services for organizing face-to-face, distance (synchronous and asynchronous) and blended learning are as follows:

1. Services for creating interactive learning content;
   A. Services for creating interactive exercises;
   B. Services for creating interactive video;
   C. Services for creating virtual whiteboards;
   D. Interactive simulation services;
2. Services for organizing and conducting an online lesson;
3. Services for creating a virtual classroom and an electronic journal.

2. Analysis of the state of ICT use by primary school teachers in Ukraine

Based on a series of studies (2019-2021) conducted at Izmail State Humanitarian University and other educational institutions, the state of ICT usage in the professional activities of primary school teachers in Ukraine was established [44].

2.1. Research methodology

The presented study was organized as a series of interrelated stages of data collection and analysis during 2019-2021. The study represented longitudinal monitoring with elements of comparative analysis. A mixed methodology was used with a predominance of quantitative data collection methods and their qualitative interpretation.

2.2. Data collection stages

2.2.1. Initial survey (spring 2019)

The sample consisted of 30 primary school teachers from the Odessa region who completed paper questionnaires containing 6 questions. The purpose of the study was to determine the general state of ICT use in professional activities [53]. Paper questionnaires contained closed-ended questions with the ability to add one's own option. A five-point scale was used for self-assessment of ICT proficiency level.

2.2.2. Extended questionnaire (March 2020)

55 primary school teachers from the city of Izmail and the Izmail district participated in a survey based at the Izmail City Teacher's House. The questionnaire questions focused on ways of acquiring ICT competence, problems of ICT implementation, frequency of use, and types of digital resources [54]. In addition to closed-ended questions, these questionnaires contained open-ended questions regarding teachers' use of online services.

Primary school teachers participated in the survey; the age range was from young specialists to experienced teachers (average age 42 years), with work experience ranging from 1 to 48 years (average experience $\sim$19 years) and qualification categories from "specialist" to "higher category specialist". The geography of the study covered urban (80%) and rural (20%) schools of the Odessa region.

2.2.3. Online survey (autumn 2020)

The sample consisted of at least 119 teachers from the closed Facebook group "Mathematics 'Morning'. Pilot". The research method was an online questionnaire with the possibility of multiple choice. The focus of the survey was on primary school teachers' awareness of online services for creating interactive exercises, educational videos, and virtual boards. The questionnaire was presented in Google form and provided for the possibility of multiple choice and adding one's own options. The study adhered to the principles of academic ethics and ensured the anonymity of respondents when processing and presenting the results [47].

2.2.4. Online survey (autumn-winter 2021)

The online survey was conducted from November to December 2021 to determine the most popular online services among teachers. 232 primary school teachers in Ukraine participated in it by filling out a questionnaire presented in a Google form and posted in professional groups on social networks [55].

2.2.5. Analysis of all-Ukrainian research (2020-2021)

At this stage, the data of the all-Ukrainian online survey of the National Academy of Educational Sciences of Ukraine (607 respondents) were studied; a comparative analysis was conducted with the results of studies by Burda and Vasylieva [56]; comparison with the study of Skvortsova et al. [57].

3. Research results

3.1. Pre-pandemic period (2019-early 2020)

According to the results of a survey of 30 primary school teachers in 2019:

- 100% of respondents owned a computer and had experience using ICT.
- The highest self-assessment was given to skills for working on the Internet (80% – 5 points) and with e-mail (90% – 4 points).
- Lower scores were found for skills related to working with the file system, text editors, presentations, and graphics.

- The lowest results were found for skills for working in professional online networks (50% – 1 point) and creating websites (90% – 1 point).

Regarding the sources of acquiring ICT competence: 10% acquired it during their studies at higher education institutions, 50% – through participation in seminars and trainings, 40% – independently.

The subsequent study (March 2020) involving 55 teachers demonstrated:

- An increase in the number of teachers who acquired ICT competence in higher education institutions (from 10% to 22%).
- 84% of teachers worked independently to improve their ICT skills.
- The main obstacles to ICT implementation were: insufficient knowledge of technologies (70%), lack of time (64%), problems with classroom material provision (66%).
- 78% of respondents constantly used ICT in their professional activities.

According to the results of the survey of teachers before the COVID-19 pandemic, teachers used ICT as follows:

- 93% printed materials for classes.
- 96% searched for educational information on the Internet.
- 98% conducted lessons using computer technology.
- Only 24% created educational and gaming content using online resources.

3.2. Pandemic period (2020-2021)

During the pandemic and distance learning:

- The most popular means of communication were Viber (88.2%), the school website (62.7%), and Google Classroom (45.5%).
- The most frequently used resources for preparing and conducting lessons were “Na Urok” (74.4%), author’s lessons on YouTube (75.8%), and “Vseosvita” (64.6%).
- The LearningApps service became the most popular for creating interactive exercises (82% of teachers knew about it, 21% used it).
- To present educational content on a virtual board, 50% of teachers were aware of Padlet, but only 16% used it.

As a result of the transition to distance learning, there was a positive trend in the use of digital platforms. Comparison 2020-2021 showed an increase in the popularity of the platforms:

- “Na Urok” from 63.6% to 80.7%.
- “Vseosvita” from 44.3% to 60.5%.
- LearningApps from 25.1% to 41%.

To create interactive exercises in mathematics, teachers use various services, including LearningApps, Liveworksheets, Wizer.me, H5P, and others. At the same time, 17.7% of respondents did not create interactive exercises for lessons.

Compared to the 2020-2021 academic year, there was a positive trend in the choice of services for creating interactive materials. In particular, the use of Liveworksheets increased from 4% to 44.6%, and Wizer.me from 0.8% to 8.8%.

Regarding the creation of educational videos, 62.4% of teachers used MS Power Point, 46.8% – Zoom, 26.3% – screen recording programs. However, 50% of respondents noted that they did not create interactive videos, although there was a positive trend in the use of relevant services: Learnis (from 2% to 20.2%), H5P (from 0.8% to 4%).

The use of virtual whiteboards increased significantly: Padlet was chosen by 66.8% of respondents compared to 16% in the previous academic year. The use of Lino.it increased from 4% to 8.3%. At the same time, 26.3% of teachers did not use virtual whiteboards.

3.3. Dynamics of ICT competencies formation among Ukrainian teachers

The results of the self-assessment of teachers' ICT competence showed that 12.4% of respondents gave themselves the maximum score, 4 points – 28.4%, 3 points – 22.2%, 2 points – 9.8%, 1 point – 5.7%, 0 points – 21.6%.

A comparative analysis of the results of the study before and during the pandemic shows that during the pandemic, primary school teachers identified gaps in the use of ICT and assessed their own level of ICT competence more objectively. There was an increase of 2.1% in the number of teachers with a good level of ICT competence and 6.6% with an average level (table 1).

Table 1
Dynamics of ICT competencies formation among Ukrainian teachers in the pre-pandemic and post-pandemic periods based on self-assessment judgments of respondents.

Level	**High (5 points), %**	**Good (4 points), %**	**Average (3 points), %**	**Insufficient (2 points), %**	**Missing (1 point / 0 points), %**
Pre-pandemic period	15.5	26.3	15.5	20.0	22.7
Pandemic period	12.4	28.4	22.1	9.8	27.3
Increase	-3.1	+2.1	+6.6	-10.2	+4.6

Regarding material and technical support, as of 2021, 88.1% of general secondary education institutions in Ukraine had computer science classrooms with over 202 thousand workplaces. However, the issues of updating computer equipment (57% of computers were purchased more than five years ago) and providing high-quality Internet connection (40% of schools do not have proper connection) remain problematic [56].

A comparative international analysis showed that Ukrainian teachers demonstrate a higher level of readiness for advanced training in the field of ICT than their Mexican colleagues. According to 2021 research, 77.3% of Ukrainian teachers have mastered at least one electronic course on the use of ICT [55], while 40.7% of Mexican teachers have never attended such courses [58].

The study confirms that the forced transition to distance learning due to the COVID-19 pandemic had a positive impact on the development of ICT competence of primary school teachers, stimulating the mastery of new digital tools for creating interactive educational content.

Analysis of Ukrainian and foreign studies shows that primary school teachers actively use ICT in their professional activities. The forced transition to distance, online, and blended learning stimulated them to improve their ICT competence, often independently mastering the tools through webinars and master classes.

Teachers' self-development in the field of ICT was aimed at mastering the basic tools necessary for organizing distance learning (Google Meet, Zoom, Google Classroom, ClassDojo, etc.). Most teachers stopped at this stage, choosing a basic set of services. However, some teachers expanded this set to include services for creating interactive and non-interactive content, which requires deeper knowledge in the field of ICT and relevant technical and methodological skills. This emphasizes the need to train teachers to use ICT while still studying in higher education.

The focus of attention of primary school teachers is on organizing the educational process (face-to-face, distance, blended) using ICT, saturating lessons with video and interactive content. For distance learning, services that offer the creation of an electronic journal and a virtual classroom, with the possibility of filling it with educational materials, interactive tasks, and tests, are useful. During face-to-face education, the teacher can offer students interactive exercises and tests, interactive videos, and meet the needs of modern students – representatives of the digital generation.

Recently, virtual environments and laboratories for students' educational research [**?**], services for creating virtual reality, and chatbots [59, 60, 61], in particular GPT, have been rapidly developing. In virtual laboratories, students can explore facts and patterns, practice methods of action, and then practice skills in a game form. Chatbots are useful both for teachers during lesson preparation and for students during project activities, for searching for information and generating questions. It is obvious that the issue of organizing face-to-face and distance lessons using ICT should be part of the training of future primary school teachers. Therefore, it is advisable to include modules on mastering online platforms and services in courses of methodological disciplines or elective disciplines during studies in higher education institutions.

4. A set of online services for organizing face-to-face, distance and blended learning

Analysis of research by Ukrainian and foreign scientists indicates the need to develop ICT competence of primary school teachers. It has been established that teachers need help not only in using hardware but also in practice-oriented training on the material of individual subjects. It is important to familiarize teachers with services for organizing face-to-face, distance and blended learning, such as creating a virtual classroom, electronic journal, interactive content, virtual whiteboards, as well as services for conducting online lessons.

Given the preferences of primary school teachers and the positive dynamics of their mastery of online services, it is advisable to provide for familiarization of future teachers with the use of ICT in the process of teaching individual subjects or integrated courses. The components of the complex of online services for organizing face-to-face, distance (synchronous and asynchronous) and blended learning are:

1. Services for creating educational interactive content:
    - Services for creating interactive exercises;
    - Services for creating interactive video;
    - Services for creating virtual whiteboards;
    - Services-interactive simulators.
2. Services for organizing and conducting an online lesson.
3. Services for creating a virtual classroom and an electronic journal.

The selection of online services was carried out taking into account the results of a longitudinal study of the preferences of primary school teachers in Ukraine. Each of them already has a Ukrainian-language library that the teacher can use without further development.

Therefore, within the framework of methodological disciplines it is advisable to familiarize future teachers with a set of online services for organizing face-to-face, distance (synchronous and asynchronous) and blended learning. This set of online services is open and can be modified and supplemented in accordance with constantly changing conditions.

4.1. Services for creating interactive educational content

We proceed from the interpretation of "educational content" as a set of content elements that are the subject of study by students. By interactive learning content we mean: 1) educational content that provides for certain actions with its elements and requires active participation of the student in the process of working with it; 2) a tool for teacher-student interaction by offering the student certain educational digital products, with the possibility of feedback in the form of an assessment of the results of learning activities 3) a set of all elements (content elements and control elements that allow moving through the content array) with which the student interacts directly or indirectly.

As the practice of modern primary school shows, there are different forms of interaction with interactive learning content; we are talking about passive, active, and research. In a passive form of interaction, a student does not change the content but only views or listens to interactive content in order to understand and memorize educational information, performing only management functions (starting and finishing work, scrolling, etc.). For example, a passive form of interaction can be observed when a student watches an instructional video prepared in advance by a teacher.

The active form of interaction involves changing the content by performing certain actions with it; in this case, the interactive learning content has two states – the original (created by the teacher) and the transformed (modified by the student). For example, when watching an interactive educational video that includes pauses for exercises, the learner is forced to apply the knowledge or methods of action gained while watching the video fragment – we have an active form of interaction with interactive content.

The exploratory form of interaction involves not just modifying content elements according to a plan or algorithm that is set externally, as in an active form of interaction, but studying an object by changing conditions while freely manipulating it. For example, when working in the PhET Interactive Simulations virtual laboratory and studying fractions, a student can set numerical values for the numerator and denominator and observe the corresponding value of the whole.

The use of interactive educational content in the learning process allows you to organize interaction with the student: present educational material, organize feedback, instantly evaluate the results of students' learning, and provide a certain amount of assistance if the student has difficulties.

Interactive content includes interactive exercises, tests, videos, virtual whiteboards, online simulations, etc. It should be noted that any learning content can be interactive if it is based on interaction with the learner.

Given the above features of the cognitive processes of the learner's personality as a representative of the digital generation, to improve the perception, understanding and memorization of educational information, visualization and clarification of educational material is required, which can be realized through the use of ICT tools, creating interesting, vivid and dynamic interactive content. The most popular interactive content among Ukrainian teachers is interactive exercises.

4.2. Services for creating interactive exercises

An interactive learning exercise is a task made in a certain online service using templates of this service, which is launched when a student logs in and is completed when he or she logs out. Interactive exercises can involve both the teacher entering the correct answer (and therefore create the possibility of instant automatic verification of the result of the student's performance of this task) and the student's open answer (in which case the teacher checks the correctness of the task himself).

In any case, an interactive exercise contains the following elements: instructions on how to perform it, how to record the result; the actual task condition; the solution and the answer (if the task is performed in a template with automatic verification, the teacher writes down the correct answers during its preparation).

It should be noted that interactive exercises performed in a template that provides automatic verification of correctness allow students to immediately receive feedback on the result of their performance, thus satisfying the need of students of the digital generation for instant gratification, as they do not want to wait for a remote result.

By creating interactive exercises in services that also include an electronic journal, the teacher receives information about each student's completion of all tasks and can monitor their progress. Of course, services that include an electronic journal allow a teacher to organize a virtual classroom by inviting students to it and offering assignments to students through this classroom. Of course, this option is useful for organizing distance and blended learning.

Online services for creating interactive exercises offer the creation of tasks in a whole range of templates that can be combined into groups. These are templates for creating tasks that require the following steps to enter the correct answer: 1) selecting and clicking on the correct answer – pointing exercises; 2) moving the elements of the task – manipulative exercises; 3) writing the correct answer – keyboard exercises; 4) naming the answer – speech exercises.

Pointing and manipulative types of exercises, in some cases also keyboard exercises, involve automatic verification of the correctness of the task by the service. It should be noted that keyboard tasks may contain an open answer followed by a teacher's check. All of the above may also apply to test tasks.

When selecting online services for creating interactive exercises, we adhered to certain requirements: Group I – requirements for creating interactive exercises; Group II – requirements for controlling their implementation and monitoring student performance.

The first group of requirements for creating interactive exercises and test tasks includes: 1) the ability to create exercises for all sections of the subject; 2) the availability of a sufficient number of platforms to diversify interactive exercises; 3) the ability to brightly design interactive exercises through the use of pictures, graphs, diagrams, audio and video materials, etc.; 4) the availability of animations, dynamism and special effects in interactive exercises; 5) the ability to create differentiated exercises by level of difficulty; 6) the ability to present a series of interactive exercises by level of advancement, where the student sees how many exercises he or she needs to complete to move to a higher level; 7) a clear and simple algorithm for students to complete interactive exercises; 8) a simple algorithm for teachers to create interactive exercises.

The second group of requirements for controlling the implementation of interactive exercises and monitoring student performance includes: 1) avoiding the possibility of students acting at random when choosing an answer; 2) availability of the function of instant and step-by-step control of the course of students' performance of a particular exercise, a series of exercises, accumulation of data on students' performance and their analysis and generalization, which allows to track the results.

We have already identified the most popular online services among Ukrainian teachers for creating interactive exercises. Here are the services we have selected: LearningApps, LiveWorksheets, and Wizer.me, H5P, Google Forms, Classtime.

4.3. Services for creating interactive video

Interactive video is a special video format that involves interaction with video content through the use of various tools. Interactive learning videos integrate additional elements into the video, such as video pauses that prompt students to complete a task and embedded hotspots that encourage students to work through the necessary learning material presented through text, images, graphs, or hyperlinks to a relevant web page.

An interactive training video is created on the basis of a ready-made training video, which is supplemented with hotspots and stops. Therefore, we believe that it is methodologically justified to adhere to the following groups of requirements when choosing online services for creating interactive video: Group III – requirements for creating an educational video; Group IV – requirements for creating "hot spots" and stops with interactive tasks, as well as monitoring the results of interactive tasks.

The third group of requirements for creating an educational video includes 1) the ability to create a video based on a multimedia presentation; 2) the ability to create a live video; 3) the ability to create a video based on a ready-made script; and 4) the duration of the created video.

The fourth group of requirements includes 1) the convenience of adding interactive content; 2) a variety of templates for creating interactive exercises; 3) control over the correctness of interactive exercises; and 4) the ability to view the current and final results of an interactive video.

So, to create a training video, we suggest choosing Microsoft Powerpoint, Canva, Renderforest, Zoom, and Microsoft Teams, and to create an interactive video, H5P and LearningApps.

4.4. Services for creating virtual whiteboards

Using online services to demonstrate educational material on a virtual whiteboard, it is possible to introduce students to organized interactive learning content on a particular topic or lesson.

Virtual whiteboard services will help teachers not only organize and conduct remote lessons in asynchronous mode but also organize and conduct educational projects. On a virtual whiteboard, a teacher can vividly and clearly present both the structural elements of a distance lesson and structural elements of the educational project and a plan for working on it. A virtual whiteboard makes it possible to visualize the course of a distance lesson by presenting the content units of the lesson in a schematic form or in the form of notes. The virtual whiteboard also helps the teacher organize and conduct a presentation (defense) of the project asynchronously in the form of students uploading videos and/or other materials and evaluating them, in particular in Padlet.

Given the purpose of distance learning, educators are mostly interested in virtual interactive whiteboards for organizing collaborative work with various content with the possibility of joint editing – Educreations, Lino.it, Padlet, Popplet. Realizing that virtual whiteboards are available on the web from IDroo, Whiteboard Fox, Padlet, NoteBookCast, Conceptboard, Groupboard, Classroomscreen, Ziteboard, Lino.it, and others, and their list is constantly expanding. Therefore, when choosing virtual whiteboards, we suggest focusing on the following group of requirements: 1) the availability of various virtual whiteboard templates; 2) the ability to present material of various formats on a virtual whiteboard; 3) the ability to involve students in viewing publications; 4) the ability for students to publish their own posts.

In accordance with our requirements, we propose to use the Padlet and Lino.it virtual whiteboard services.

4.5. Interactive simulation services

We consider interactive simulators as a digital service that creates visualization capabilities through the use of models of abstract objects that are studied and researched. In this way, abstract objects/concepts, processes, and situations are modeled in a virtual environment, the study and research of which leads to a significant learning outcome in the form of discovering patterns, modes of action, rules, generalizations, etc. These simulations not only provide purely educational content but also have a shell for implementing the educational experience and provide a game format. Thus, we consider interactive simulations to be resources for teaching with simulations, as well as those that involve the use of immersive technologies – virtual and augmented reality.

We divide interactive simulators into two groups: virtual laboratories and augmented and virtual reality.

When choosing virtual laboratories, we suggest taking into account the following requirements: 1) the possibility of observing a new concept or method of action by setting certain conditions by the student; 2) the possibility of visualizing the result in different formats; 3) bringing students to the generalization of a concept or method of action; 4) the possibility of developing a skill or skill in applying a new method of action; 5) the possibility of applying a new method of action when performing tasks from simple to complex; 6) the possibility of organizing the study of a new concept or method of action both in symbolic and visual form. In accordance with these requirements, we suggest using such services as PhET and GeoGebra.

The teacher can create and/or use AR and VR with the help of Google Art, and H5P.

Unlike VR, which helps to immerse oneself in an artificial and simulated world and act in it, AR is more connected to the real physical world. AR is a technology in which the user's perception of the real world is enhanced and supplemented with additional information from computer models, allowing the user to stay connected to the real environment. It is known that the main difference between AR and VR is that in VR the user is completely immersed in the artificial world and is separated from the real world, and in AR the system brings the digital device to the user's real working environment as an auxiliary tool for a comprehensive study of the object [62].

To effectively use VR in teaching younger students, teachers need special equipment and paid programs that are not available in all educational institutions. A simplified option that allows teachers to demonstrate VR elements is virtual tours. The issue of the didactic possibilities of virtual tours in teaching junior schoolchildren is studied by Vasiutina [63]. The author proposes to use the Google Art and Culture application for younger students to view the expositions of the world's best museums [63].

In our opinion, virtual tours are not the only possible example of VR use. For example, lessons can be "emotionally embellished" by incorporating certain AR elements when working on learning tasks. For example, to create a positive emotional background in math lessons, in order to help students visualize the situation described in the task, you can create a link to the corresponding video fragment that illustrates the plot of the task.

AR can also be used as a means of implementing a differentiated approach: by pointing the device at a certain mark, a student can receive either instructions for solving a problem, a detailed algorithm of actions, or a ready-made solution and analyze it or test themselves, or, conversely, receive a task of a higher level of complexity.

With A-Frame and H5P, teachers can create their own AR, depending on the topic and content of the learning tasks, in the following ways: by overlaying images, audio and video materials, 3D models on a real image that may be contained in textbooks, workbooks, or individual drawings.

4.6. Services for organizing and conducting an online lesson

Synchronous distance learning is impossible without services for organizing real-time video conferencing. Based on the preferences of teachers in choosing services for organizing online lessons, we suggest that you meet the following requirements: 1) the ability to schedule a meeting in advance and synchronize it with the calendar; 2) the duration of the conference and the maximum number of participants; 3) the ability to demonstrate the screen; 4) the availability of the whiteboard tool; 5) the ability to record the conference; 6) the ability to communicate in chat; 7) the ability to create virtual rooms for organizing group work.

So, for online lessons, we suggest using Zoom, Google Meet, and Microsoft Teams. These services, chosen on the basis of our surveys of teachers, correlate with the results of the study by Burda and Vasylieva [56], who argue that teachers use Zoom most actively; Skype was second in 2020 (over 20%), and in 2021 it was replaced by Google Meet (54.2%).

4.7. Services for creating a virtual classroom and electronic journal

We understand a virtual classroom as the organization of the educational process on an appropriate platform using tools that create certain opportunities. These include: connecting students to the virtual classroom; filling it with educational materials and interactive content; uploading students' work; checking uploaded work by the teacher; recording the results of students' learning activities in an electronic journal: both recording the results of interactive tasks automatically checked by the service and tasks checked by the teacher; organizing and conducting video conferences.

When choosing services, we suggest that you meet the following requirements: 1) the ability to create a virtual classroom: selection of exercises or a series of exercises for a given lesson and a given class; 2) the availability of a bank of interactive exercises that can be used at any time without creating your own; 3) the ability of the teacher to further work with the results in an electronic journal.

Taking into account the results of a survey of teachers on the choice of services for creating a virtual classroom and an electronic journal, we have chosen LearningApps, Google Classroom, Padlet, ClassDojo, Classtime, Wizer.me, Liveworksheets. It should be noted that Google Classroom has all of the above tools that allow for a holistic presentation of a virtual classroom, and the services (LearningApps, Padlet, ClassDojo, Classtime, Wizer.me, Liveworksheets) help teachers focus on one or more aspects of creating a virtual classroom that requires the use of other services.

5. Results of experimental verification of the complex

5.1. Experimental research methodology

The experimental base included 157 applicants for the bachelor's degree, including 78 people at Izmail University and 79 people at the Bohdan Khmelnytsky National University of Cherkasy (hereinafter referred to as ChNU). The experimental work took place in two stages: ascertaining and formative.

5.2. The ascertaining stage

The purpose of the ascertaining stage was to determine the level of readiness of future primary school teachers to use ICT in the process of teaching younger schoolchildren who are candidates for higher education in the specialty 013 Primary Education, for the selection of control and experimental groups. Since the experimental work lasted for three academic years (2020-2023), the ascertaining experiment was held every year before the implementation of experimental training. The implementation of the aim of the ascertaining experiment involved surveying students on the state of awareness of online services.

The survey of students of the 3rd and 2nd (shortened term of study) courses of the Izmail University was conducted before studying the module "ICT in teaching mathematics to younger schoolchildren" within the framework of the normative discipline "Methodology of teaching mathematics in primary school" and students of the ChNU during the 2020-2021 academic year, 2021-2022 academic year and 2022-2023 academic year.

The ascertaining experiment was implemented using diagnostic tools, in particular, surveying students on their awareness of online services. The results obtained indicate that students are familiar with the most popular services (LearningApps, Padlet, Canva, etc.) and with those with which they interact during distance learning in higher education institutions (Google Meet, Google Classroom, Google Forms, Zoom, Microsoft Teams); an insufficient level of formation of the skills of higher education applicants to use the outlined services was established.

The student survey was conducted during the 2020-2021 academic year, 2021-2022 academic year and 2022-2023 academic year in two series: 1) students of the 3rd and 2nd (shortened term of study) courses of the Izmail University before studying the module "ICT in teaching mathematics to younger schoolchildren" within the framework of the normative discipline "Methodology of teaching mathematics in primary school" and students of the ChNU; 2) students of subgroups I and II of the 4th year of study at Ushynsky University at the beginning of mastering free choice disciplines.

1. In 2020-2021, 100% of students of Izmail University and ChNU were knowledgeable to use ICT in teaching younger students. However, only 33% of IDGU students and 32% of ChNU felt the need to use online services. Only 25% of Izmail University students and 24% of ChNU were directed to finding new digital tools and varying digital resources. Students were familiar with such services as LearningApps, Google Forms, Classtime, Canva, Padlet, GeoGebra, Google Arts and Culture, Zoom, Google Meet, Microsoft Teams, ClassDojo and Google Classroom. The level of skills in these services was assessed as high (0%), sufficient (17% of Izmail University, 16% of ChNU), average (58% of Izmail University, 60% of ChNU), low (25% of Izmail University, 24% of ChNU). Skills were acquired during studies at higher education institutions (42% of Izmail University, 52% of ChNU) and independently (58% of Izmail University, 48% of ChNU).
   The results of our study are generally consistent with those of Villena Taranilla et al. [34], who surveyed Spanish students – future primary school teachers and found that their mastery of educational ICT tools is only at the "satisfactory" level. At the same time, they revealed a positive attitude towards ICT: students are aware of the importance of digital skills for their future profession and seek to develop them. The authors emphasize the need to strengthen the development of this competence in curricula, especially through the integration of pedagogical and technological knowledge.
2. In 2021-2022, 100% of Izmail University and ChNU students were oriented towards using ICT. However, only 45% of Izmail University students and 42% of ChNU felt the need for online services. 34% of Izmail University students and 38% of ChNU were directed towards finding new digital tools. The list of services remained unchanged. The level of skills in services was assessed as high (0%), sufficient (21% of Izmail University, 19% of ChNU), average (55% of Izmail University, 58% of ChNU), low (24% of Izmail University, 23% of ChNU). Skills were acquired during studies at higher education institutions (48% of Izmail University, 46% of ChNU) and independently (52% of Izmail University, 54% of ChNU).
3. In 2022-2023, 100% of Izmail University and ChNU students were oriented towards using ICT. 68% of Izmail University students and 64% of ChNU felt the need for online services. 48% of Izmail University students and 46% of ChNU were directed towards finding new digital tools. The list of services remained unchanged. The level of skills in working with services was assessed as high

(0%), sufficient (24% of Izmail University, 25% of ChNU), average (56% of Izmail University, 57% of ChNU), low (20% of Izmail University, 18% of ChNU). Skills were acquired during studies at higher education institutions (40% of Izmail University, 43% of ChNU) and independently (60% of Izmail University, 57% of ChNU). Based on the data, it was found that the level of skills in using online services of Izmail University and ChNU students is approximately the same. The study participants were combined into experimental (EG1, EG2, EG3) and control groups (CG1, CG2, CG3). The homogeneity of the level of students' readiness to use ICT was proven using the χ^2-Pearson criterion. The null hypothesis of no differences between the distributions of readiness levels of students of Izmail University and ChNU was accepted (χ^2-Pearson = 0.67, p = 0.967).

5.3. The formative stage

The developed complex has been implemented in the methodological training of students majoring in Primary Education at the Izmail University.

Students of Izmail University mastered the developed complex while studying a separate module "ICT in Teaching Mathematics to Primary School Students" as part of teaching of the normative discipline "Methods of teaching mathematics in primary school".

Experimental training allowed students to explore the possibilities of using a set of online services at different stages of a primary school mathematics lesson. They gained experience in delivering a remote math lesson in Google Classroom/ClassDojo or on the Padlet/Lino.it virtual whiteboard. It should be noted that these virtual classrooms or virtual whiteboards contain or provide links to interactive exercises, simulations, and instructional videos. It should be emphasized that even if a link to a video or task is provided, the student automatically goes to a certain service and sends the results of his or her work to the teacher in the form of a screenshot of the page where the work has already been evaluated. It is also possible that the teacher can view the results of individual tasks directly in the service in which the task was created, provided that interactive tasks are sent through the virtual classroom of this service (LearningApps, Classtime, and Liveworksheets). It should be noted that the acquired competencies in organizing face-to-face, distance and blended learning using a set of online services were applied by students during the simulation of future professional activities in seminars and laboratories.

Pedagogical practice shows that over the past two years, teachers have mostly used real-time distance learning to conduct online lessons. The most common services for online math lessons are Google Meet, Zoom, and MS Teams. These lessons also involve interactive exercises that can be posted in the above services, and therefore the option of feedback from the teacher may be the same.

As a result of mastering this module, students were able to complete creative projects – to create tasks using online services in accordance with the peculiarities of the structure of a combined mathematics lesson in primary school. In completing the assignments, students demonstrated awareness of using online services and templates for creating interactive exercises of these services, understanding the features of selecting appropriate service templates for a particular task; the possibility of combining online services when organizing a distance lesson, compensating for the disadvantages of certain services with the advantages of others. Students posted their completed assignments in the Google Classroom.

The purpose of the formative stage of the study was to determine the effectiveness of special training of future primary school teachers to work with the above complex of online services.

In the control groups (CG1-3), the training of future teachers to use ICT was limited to studying the issue "Teaching aids" within the topic "Organization of mathematics teaching in primary school". In the experimental groups (EG1-3), the training involved mastering the module "ICT in teaching mathematics to younger schoolchildren", which included the following topics: 1) Services for creating educational interactive content in mathematics (1 seminar, 1 laboratory session); 2) Services for creating a virtual classroom and an electronic journal (1 lecture); 3) Online services for organizing a distance lesson (1 seminar session).

Particular attention was paid to the educational material prepared on the basis of electronic courses from the Zmist.ua website. The following organizational and pedagogical conditions were implemented: 1) updating the content of the work programs of methodological disciplines and elective courses with modules related to ICT; 2) training teachers to use ICT.

At the formative stage of the experiment, the following tasks were solved:

1) researching the capabilities of online services for creating interactive content, organizing online lessons, creating a virtual classroom and working with an electronic journal;
2) demonstrating a system for organizing a mathematics lesson with a combination of online services;
3) implementing individual creative projects;
4) determining the level of readiness of future teachers to use ICT;
5) analyzing students' motivation to use online services and reflecting on the acquired competence.

Results of mastering the module "ICT in teaching mathematics to younger schoolchildren" Students of EG1-3 successfully completed creative projects, creating tasks using online services in accordance with the structure of a combined mathematics lesson in primary school. They demonstrated awareness of using online services, understanding the selection of appropriate templates and the possibility of combining services for organizing a distance lesson. The completed tasks were placed in the virtual environment of Google Classroom, which indicates the creation of an educational environment in higher education institutions by introducing ICT in the training of future teachers.

Students of CG also completed projects to create interactive mathematics exercises without special training in the use of online services. Students of EG1-3 actively participated in student conferences, reporting on the use of ICT in mathematics lessons in primary school. The results of the implementation of creative projects are summarized in table 2.

Table 2
Results of students' creative projects.

School year	Groups	Level				Total
		low	average	sufficient	high	
2020–2021	EG_1 Abs.val	3	11	7	3	24
	EG_1 %	12.5	46	29	12.5	100
	CG_1 Abs.val	6	15	4	0	25
	CG_1 %	24	60	16	0	100
2021–2022	EG_2 Abs.val	4	12	10	3	29
	EG_2 %	14	41	35	10	100
	CG_2 Abs.val	5	15	5	1	26
	CG_2 %	19.2	58	19	3.8	100
2022–2023	EG_3 Abs.val	2	11	9	3	25
	EG_3 %	8	44	36	12	100
	CG_3 Abs.val	4	15	7	2	28
	CG_3 %	14,3	53,6	25	7,1	100

To prove the differences in the results of the experimental and control groups of students of Izmail University and ChNU, the χ^2-Pearson criterion was used at the significance level $\alpha = 0.05$. Two hypotheses were formulated:

H0: there are no differences between the distributions of students of the experimental and control groups of the two universities by levels of creative projects.

H1: there are differences between the distributions of students of the experimental and control groups of the two universities by levels in the implementation of creative projects.

Calculation results: χ^2=8.407 at p=0.38 ($p \leq 0.05$). We accept the alternative hypothesis, which indicates the presence of differences between the distributions of students of the experimental and control groups of two universities by levels in the performance of creative projects. The V-Cramer index is 0.231, which for df=3 indicates the average effect size.

At the control stage, a comparative analysis of the research results was carried out using statistical data processing to assess the effectiveness of the experiment.

The summarized results of the implementation of the adaptive model of forming the readiness of future primary school teachers to use ICT are presented in the table 3.

Table 3
The effectiveness of the research-experimental approach: summarized research results.

School year	Groups	Level								Total
		low		average		sufficient		high		
		A	F	A	F	A	F	A	F	
2020–2021 s.y	EG_1 Abs. value	6	3	14	11	4	7	0	3	24
	EG_1 %	25	12.5	58	46	17	29	0	12.5	100
	CG_1 Abs. value	6	6	15	15	4	4	0	0	25
	CG_1 %	24	24	60	60	16	16	0	0	100
2021–2022 s.y	EG_2 Abs. value	7	4	16	12	6	10	0	3	29
	EG_2 %	24	14	55	41	21	35	0	10	100
	CG_2 Abs. value	6	5	15	15	5	5	0	1	26
	CG_2 %	23	19.2	58	58	19	19	0	3.8	100
2022–2023 s.y	EG_3 Abs. value	5	2	14	11	6	9	0	3	25
	EG_3 %	20	8	56	44	24	36	0	12	100
	CG_3 Abs. value	5	4	16	15	7	7	0	2	28
	CG_3 %	18	14.3	57	53.6	25	25	0	7.1	100

The reliability of the results was tested using the χ^2 Pearson criterion (significance level $\alpha = 0.05$) with the formulation of two hypotheses:

H0: there are no differences between the distributions of readiness levels in the experimental and control groups.

H1: there are statistically significant differences between the distributions of readiness levels in the studied groups.

The results of the calculations are presented in the table 4.

Table 4
Results of χ^2-Pearson calculations.

Pearson's χ^2	*df*	Asymptotic significance
8.685[a]	3	0.034
15.994[a]	3	0.001

According to the results of the calculations ($p \leq 0.05$ and $p \leq 0.001$), we reject the null hypothesis and take into account the alternative hypothesis: there are differences between the distributions of the levels of readiness of future primary school teachers to use ICT in teaching younger schoolchildren of the experimental and control groups.

The effect size was estimated using the V-Cramer index (table 5).

Table 5
Interpretation of the effect size of the V-Cramer index for df=3,

V Kramer	*df=3*	Effect size
0.235	0.17–0.28	average
0.250	0.17–0.28	average

Based on the presented data (figure 1), it was established that the implementation of the developed complex of online services demonstrates higher efficiency compared to traditional approaches. Experimental training in the use of a complex of online services statistically reliably provides better results in

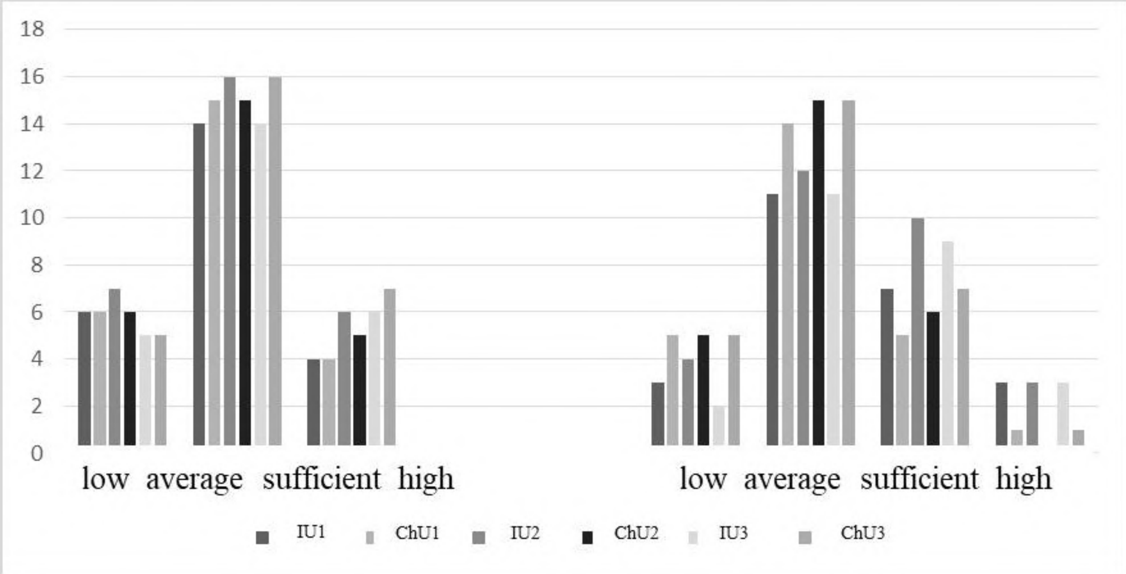

Figure 1: Dynamics of growth of quantitative characteristics of readiness levels of future primary school teachers to use ICT in teaching younger schoolchildren.

the formation of teachers' readiness to use information and communication technologies in professional activities.

6. Discussion of research findings and debatable issues

Based on the presented study regarding ICT usage in the professional activities of primary school teachers in Ukraine, several key conclusions:

1. Positive impact of the pandemic on ICT competency development – the forced transition to distance learning became a catalyst for the development of teachers' digital skills. This observation is supported by statistical data showing increased usage of various digital platforms and services.
2. Self-education as the primary path to ICT competency acquisition – the research shows that a significant portion of teachers (84%) work independently to improve their ICT skills rather than acquiring them during their studies at higher education institutions.
3. Deepening differentiation among teachers – some educators stopped at the basic level of ICT usage, while others expanded their arsenal of digital tools and began creating interactive content.
4. More objective self-assessment of competency levels – during the pandemic, primary school teachers more realistically evaluated their own skills, identifying gaps in their ICT usage.
5. Based on the results of a survey of teachers about their motivation for choosing online services and a comparative analysis of the services' capabilities, we selected the following services (LearningApps, Liveworksheets, Wizer.me, Classtime, Google Forms, H5P, Google Classroom, ClassDojo, Padlet, Lino.it, Renderforest, Canva, Zoom, Google Meet, Microsoft Teams, PhET, GeoGebra, Google Art), which form a set of online services for organizing full-time, distance and blended learning of open type, that is, in the process of professional activity, primary school teachers have the opportunity to modify it by adding new online services with greater educational opportunities. Therefore, there is a need for future teachers to master the complex of services in the process of professional training in higher education institutions, in particular when mastering methodological disciplines that develop the ability to use ICT in the educational process, taking into account the specifics of subjects and integrated courses.
6. The effectiveness of implementing the developed complex of online services was verified during a pedagogical experiment, which included ascertaining and formative stages. The ascertaining

stage was repeated over three academic years and demonstrated growth in the need for online services throughout the research period – there is a significant positive trend among students who felt the need to use online services: from 33% in 2020-2021 academic year to 68% in 2022-2023 academic year (Izmail University) and from 32% to 64% (ChNU).
7. Increased motivation to search for new digital tools – the percentage of students directed towards finding new digital tools increased from 25% to 48% (Izmail University) and from 24% to 46% (ChNU) over three years.
8. The results of the formative experiment convincingly demonstrate the effectiveness of specialized training for students in using online services in their professional activities. The results of creative projects demonstrate a significant difference between experimental and control groups, which is statistically confirmed using the χ^2-Pearson criterion.
9. Stable set of online services – the list of online services used by students remained unchanged throughout the study period, which may indicate the formation of a "core" of the most popular and convenient services. However, it should be noted that the conditions for using these services changed somewhat over the years of experimental work, which was emphasized to the students. Additionally, the list of services was supplemented with new ones, but the core services remained unchanged.

Debatable issues can be identified:

1. The research results show that teachers often master a basic set of services and stop at this level. This raises the question: what is more important in a rapidly changing digital environment – deep knowledge of a limited set of tools or superficial familiarity with a wide range of digital resources?
2. The study shows that only 22% of teachers acquired ICT competency in higher education institutions (although this is an increase from 10% in previous data). This raises the question: how effectively are higher education institutions preparing future teachers to use modern digital technologies? Should teacher training programs be revised considering the rapid digitalization of education? We are confident that teacher training programs should include not only individual modules on the use of ICT in methodological courses, but also separate disciplines aimed at equipping future teachers with digital competence.
3. The study does not answer the question: how sustainable are the ICT skills acquired during training? Will the level of proficiency in these skills decrease after course completion, and will students apply these skills in their future professional activities?
4. This the question: how ready are the higher education institution teachers themselves to implement ICT in the preparation of future teachers? What is their level of digital competency?

Overall, despite certain methodological limitations, the study provides valuable information about the dynamics of ICT competency development among Ukrainian primary school teachers and emphasizes the need for a systematic approach to implementing digital technologies in education.

7. Prospects for further research

The conducted study confirms the effectiveness of implementing a specialized ICT module in the training of future primary school teachers. However, it also reveals a number of unresolved issues that require further investigation. First, a longitudinal study is needed to assess the sustainability and practical application of acquired ICT competencies after graduation and during the initial stages of professional activity. Second, the digital competency of higher education instructors should be examined, particularly its influence on the development of students' ICT skills. Third, there is a need to develop and validate a model that effectively integrates formal education and self-directed learning in forming digital literacy. These directions will help to deepen understanding of ICT integration in teacher education and support the development of more effective training strategies aligned with the demands of modern education.

Declaration on Generative AI

Artificial intelligence or tools using artificial intelligence were not used in the preparation of the manuscript.

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Rapid digital competence development through emergency remote teaching: a three-wave analysis of teacher training during COVID-19

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Abstract

The COVID-19 pandemic necessitated immediate digital transformation in education, revealing critical gaps in teachers' technological competencies. This study examines a rapid-response professional development program implemented across three waves during March-April 2020, engaging 1,500 registered Ukrainian educators. The five-day intensive course addressed essential cloud-based teaching competencies through Google Workspace tools. Data analysis reveals a 54.4% completion rate among the 1,029 active participants, with subsequent implementation tracking showing marked improvement in technology adoption. Post-training surveys (n=263) demonstrate a shift from 11.8% independent task management to 82.5% conducting synchronous online classes by 2021. The research identifies critical implementation challenges including technical literacy barriers, collaborative document management difficulties, and participant engagement patterns. Two additional face-to-face cohorts (n=91) provided comparative data on instructional modality effectiveness. Longitudinal assessment indicates sustained behavioral change, with 56.7% of teachers adopting previously unused digital tools. These findings inform emergency professional development design, suggesting optimal participant cohort sizes, prerequisite assessment protocols, and structured deadline management. The study contributes empirical evidence on rapid competency development under crisis conditions, with implications for resilient educational system design.

Keywords

emergency remote teaching, teacher professional development, digital competence, cloud-based learning, COVID-19 education response, Google Workspace for Education

1. Introduction

The global COVID-19 pandemic created unprecedented disruption in educational systems worldwide, forcing an immediate transition from traditional classroom instruction to emergency remote teaching [1]. This sudden shift exposed significant disparities in educators' digital competencies [2, 3, 4] and their preparedness to deliver quality instruction through online modalities [5, 6, 7, 8, 9, 10]. Ukrainian educational institutions faced particular challenges, as teachers had minimal preparation time to adapt pedagogical practices developed over decades for face-to-face instruction.

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The "Procedure for the professional development of pedagogical and scientific-pedagogical workers" identifies distance learning as an approved professional development modality, specifically emphasizing information and communication technology integration and digital competence development as priority areas [11]. This regulatory framework provided the foundation for rapid deployment of professional development initiatives during the quarantine period.

Prior research demonstrates varying levels of digital literacy among educators before the pandemic [12, 13]. While some institutions had initiated technology integration programs, systematic preparation for fully online instruction remained limited. The pandemic accelerated a digital transformation that might otherwise have taken years to implement, compressing adoption timelines from months to days [14].

This study examines the design, implementation, and outcomes of an intensive professional development program delivered to Ukrainian educators during the initial pandemic response period. The research addresses three primary questions: (1) What instructional design features facilitate rapid competency development under crisis conditions? (2) How do participant engagement patterns differ between distance and face-to-face modalities? (3) What sustained behavioral changes result from emergency professional development interventions?

2. Theoretical framework

Digital competence encompasses technical skills, pedagogical knowledge, and adaptive capacity required for effective technology integration in teaching and learning processes [15]. The European Framework for the Digital Competence of Educators (DigCompEdu) identifies six competence areas: professional engagement, digital resources, teaching and learning, assessment, empowering learners, and facilitating learners' digital competence [16].

Emergency remote teaching differs fundamentally from planned online learning in design time, preparation, and support structures [17]. While planned online courses undergo systematic instructional design processes, emergency remote teaching requires rapid adaptation of existing materials and methods. This distinction has significant implications for professional development approaches.

Cloud-based platforms provide scalable, accessible infrastructure for educational delivery [18, 19]. Google Workspace for Education emerged as a widely adopted solution during the pandemic, offering integrated tools for communication, collaboration, content creation, and classroom management [20]. Research indicates that successful cloud technology adoption requires both technical proficiency and pedagogical recontextualization [21, 22, 23].

Previous implementations of cloud-based learning environments demonstrate the importance of scaffolded support and gradual complexity increases [15, 24]. However, pandemic conditions eliminated opportunities for such gradual adoption, necessitating compressed training timelines and simultaneous skill development across multiple competency areas.

Crisis-driven professional development differs from traditional models in urgency, scope, and evaluation criteria [25, 26]. Effective emergency training programs share several characteristics: focused objectives, practical application emphasis, peer support mechanisms, and immediate implementation opportunities [27, 28].

Adult learning principles suggest that relevance, experience integration, and problem-centered approaches enhance engagement and retention [29, 30]. These principles become particularly salient when participants face immediate application requirements and high-stakes implementation contexts.

3. Methodology

3.1. Course design and development

The certificate educational program "Information systems and cloud technologies in the educational process" was developed within specialty 126 "Information systems and technologies" at Zhytomyr

Polytechnic State University [31]. The course "Cloud technologies in the educational process in quarantine" adapted existing content for emergency deployment [32].

Course objectives focused on practical competencies: (1) understanding cloud service models and architectures; (2) utilizing Google Workspace tools for instruction; (3) creating and managing digital content; (4) implementing online assessment strategies; (5) establishing virtual classroom environments.

Content delivery employed an asynchronous model with structured daily modules. Each module included theoretical materials, video demonstrations, practical exercises, and collaborative activities. Assessment relied on task completion rather than traditional testing, emphasizing application over memorization.

3.2. Participant recruitment and demographics

Three implementation waves occurred: March 30-April 3, 2020 (Wave 1), April 6-10, 2020 (Wave 2), and April 13-17, 2020 (Wave 3). Registration utilized online forms distributed through educational networks and official channels.

Participants represented diverse educational sectors: general secondary education (n=499), preschool education (n=16), higher education (n=70), vocational education (n=82), educational administration (n=94), and other roles (n=55). Geographic distribution included all Ukrainian regions, with 40 higher education institutions represented.

3.3. Data collection and analysis

Multiple data sources informed the analysis:

1. Registration and completion records (n=1,500 registered, n=816 completed).
2. Task submission timestamps and interaction logs.
3. Post-course evaluation surveys.
4. Follow-up surveys with first-year university students (n=263) regarding their secondary school experience.
5. Comparative data from face-to-face implementations (n=91).

Quantitative analysis employed descriptive statistics and completion rate calculations. Qualitative data from open-ended survey responses underwent thematic analysis to identify implementation challenges and success factors.

4. Results

4.1. Participation and completion patterns

Table 1 presents participation statistics across implementation waves.

Table 1
Participation and completion rates by implementation wave.

Metric	Wave 1	Wave 2	Wave 3	Total
Registered participants	500	600	400	1,500
Active participants	367	381	281	1,029
Course completers	296	274	246	816
Completion rate (%)	80.7	71.9	87.5	79.3

The 31.4% attrition between registration and active participation resulted primarily from technical issues: incorrect email addresses (n=113), inability to access platforms, and external time constraints. Among active participants, the overall completion rate of 79.3% exceeded typical MOOC completion rates, suggesting high motivation and perceived relevance.

4.2. Implementation challenges

Analysis identified five primary challenge categories:

1. *Technical literacy barriers:* Participants struggled with basic digital tasks including screenshot capture, file uploads, and navigation between platforms. Despite step-by-step instructions, repeated questions about identical procedures consumed significant instructor time.
2. *Collaborative document management:* Tasks requiring shared editing generated confusion and occasional conflicts. Participants inadvertently modified others' content or deleted existing work, particularly in group presentation exercises where all participants edited simultaneously.
3. *Time management:* Asynchronous deadlines created cascading delays when participants failed to complete prerequisite tasks. Late submissions affected collaborative exercises, reducing learning opportunities for punctual participants.
4. *Instructional clarity:* Despite comprehensive written materials, participants frequently requested clarification on previously explained concepts. This pattern suggests cognitive overload or insufficient processing time for complex technical information.
5. *Attribution understanding:* Academic collaboration concepts proved challenging, with participants interpreting peer editing as criticism rather than constructive engagement.

4.3. Learning outcomes and artifacts

Participants produced diverse learning artifacts demonstrating concept application:

- Mind maps covered subject-specific topics including mathematics, biology, language learning, and computer science. Visual quality and structural sophistication varied, but all demonstrated basic competency with collaborative tools (figure 1).

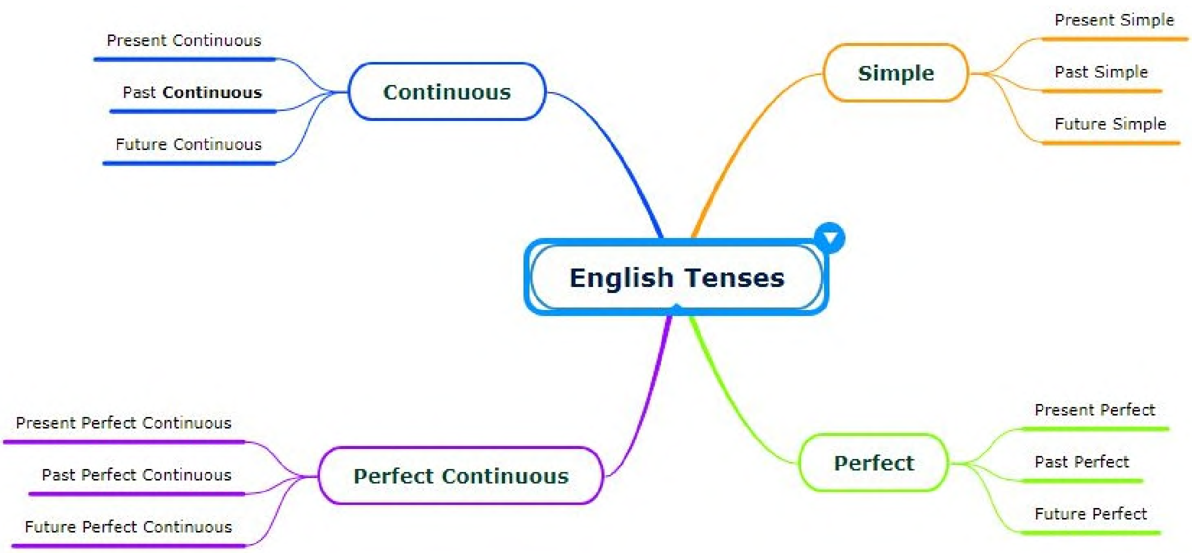

Figure 1: An example of a mind map for learning foreign languages, created by students during a distance learning course.

- Presentations utilized various cloud-based platforms, with content ranging from lesson introductions to complete instructional modules (figure 2). Technical proficiency improved markedly between initial and final submissions.
- Website creation exercises yielded functional educational sites, though design sophistication varied considerably. Most participants achieved basic functionality requirements.

Figure 2: Example of a presentation created by students during a distance learning course.

4.4. Comparative analysis: distance versus face-to-face delivery

Two face-to-face implementations (August 25-28, 2020; September 14-18, 2020) with 91 participants provided comparative data. Face-to-face participants demonstrated similar challenge patterns: inattention to instructions, difficulty with screen capture procedures, and collaborative task confusion.

However, face-to-face delivery enabled immediate clarification and peer support, reducing time to task completion. Physical presence also increased accountability and reduced attrition rates.

4.5. Long-term impact assessment

Follow-up surveys with university freshmen (September 2021) assessed sustained changes in secondary school instruction. Results indicate substantial shifts in instructional delivery methods:

- March-April 2020 (pre-intervention):
  - Independent task completion: 11.8%
  - Material distribution via messaging apps: 35.7%
  - Synchronous online instruction: 52.5%
- September 2020-May 2021 (post-intervention):
  - Independent task completion: 3.8%
  - Material distribution via messaging apps: 13.7%
  - Synchronous online instruction: 82.5%

The data reveal a 30 percentage point increase in synchronous online instruction, suggesting successful technology adoption and sustained behavioral change.

5. Discussion

The compressed timeline necessitated design decisions prioritizing immediate applicability over comprehensive coverage. Task-based assessment proved effective for skill demonstration while reducing evaluation burden. Collaborative exercises, despite implementation challenges, provided authentic practice opportunities mirroring actual teaching contexts.

Success factors included clearly defined daily objectives, multimedia instructional materials, and flexible support mechanisms. The registration-to-completion pipeline revealed critical failure points requiring targeted interventions in future implementations.

High completion rates among active participants suggest strong intrinsic motivation driven by immediate professional needs. The pandemic context created authentic urgency absent in traditional professional development programs. Participants recognized direct connections between course content and daily teaching challenges.

However, engagement patterns revealed concerning behaviors including insufficient attention to instructions and repeated requests for previously provided information. These patterns suggest cognitive overload or inadequate metacognitive strategies for managing complex technical learning.

The three-wave implementation demonstrated both scalability potential and resource limitations. Instructor workload increased exponentially with participant numbers, particularly given repetitive support requests. Future implementations should incorporate automated support systems and peer mentoring structures.

Sustained behavioral change evidenced in follow-up data validates the intervention's effectiveness. However, long-term support mechanisms remain necessary for continued skill development and adaptation to evolving technologies.

Several design principles emerge from this analysis:

1. Modular content architecture – self-contained daily modules accommodate varying participation patterns and technical difficulties.
2. Progressive complexity – initial tasks should establish baseline competencies before introducing collaborative elements.
3. Redundant communication channels – multiple information delivery methods account for varying learning preferences and technical limitations.
4. Embedded assessment – task completion as assessment reduces additional cognitive burden while providing authentic performance evidence.
5. Community support structures – peer networks sustain motivation and provide distributed support capacity.

6. Limitations

Several limitations constrain generalizability. Self-selection bias affects participant composition, as motivated educators were more likely to register and complete the course. The Ukrainian educational context may not reflect conditions in other national systems. Follow-up data collection relied on student perceptions rather than direct teacher observation.

Technical infrastructure assumptions may not hold in resource-constrained environments. The study period coincided with initial pandemic responses when motivation for change peaked. Subsequent "pandemic fatigue" might yield different engagement patterns.

7. Conclusions

This study demonstrates the feasibility of rapid digital competency development under crisis conditions. The intervention successfully prepared 816 educators for emergency remote teaching within a compressed five-day timeline. Key success factors included relevant content, practical focus, and immediate application opportunities.

Critical design considerations for emergency professional development include:

- Realistic scope definition acknowledging time and cognitive constraints.
- Pre-assessment protocols identifying baseline competencies.
- Structured collaboration with clear role definitions.

- Technical support scaling proportional to participant numbers.
- Post-training support sustaining initial gains.

The research contributes empirical evidence on emergency professional development effectiveness, informing future crisis response strategies. As educational systems develop resilience frameworks, rapid competency development mechanisms become essential infrastructure components.

Future research should examine optimal cohort sizes, investigate cultural factors affecting technology adoption, and develop automated support systems reducing instructor burden. Longitudinal studies tracking skill retention and evolution would inform sustained professional development approaches.

The COVID-19 pandemic accelerated educational digitalization by several years. While crisis-driven transformation creates challenges, it also reveals latent capacity for rapid adaptation. This study's findings suggest that carefully designed interventions can catalyze lasting positive change even under adverse conditions.

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Declaration on Generative AI

The authors used Claude Opus 4 to translate the article from Ukrainian into English.

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The use of artificial intelligence in educational and scientific practice: the literature review

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Abstract

The rapid integration of artificial intelligence (AI) into educational and scientific domains represents a paradigmatic shift in how knowledge is created, disseminated, and applied. This comprehensive literature review synthesizes recent developments (2018-2025) in AI applications across education and scientific research, with particular emphasis on emerging trends in generative AI, explainable AI (XAI), and ethical frameworks. Through systematic analysis of international literature, we identify cross-cutting themes including personalized adaptive learning, methodological innovations in scientific discovery, and critical ethical challenges. The review reveals that while AI technologies – particularly large language models (LLMs) and intelligent tutoring systems (ITS) – demonstrate transformative potential for personalized education and accelerated scientific discovery, their implementation raises significant concerns regarding algorithmic bias, data privacy, and educational equity. We examine the evolution from AI-directed to AI-empowered learning paradigms, the emergence of multi-agent systems for educational personalization, and the critical role of explainable AI in building trust and accountability. Our analysis highlights persistent gaps between theoretical frameworks and practical implementation, particularly in under-resourced educational contexts. The paper concludes by proposing a research agenda that prioritizes ethical AI deployment, interdisciplinary collaboration, and the development of context-responsive applications that balance technological innovation with human-centered pedagogical values.

Keywords

artificial intelligence in education, AI ethics in learning, explainable AI in education, personalized adaptive learning, generative AI applications, algorithmic bias in AIED, educational equity and AI, human-AI collaboration in teaching, AI-driven scientific discovery, multi-agent systems in education, ethical AI frameworks, AI literacy for educators, digital divide in AI-enhanced learning, future of teaching and learning with AI

1. Introduction

The technological revolution currently transforming global society extends profoundly into education and science, with artificial intelligence (AI) playing an increasingly central role in reshaping traditional paradigms of teaching, learning, and research [1, 2, 3, 4, 5, 6]. The AI equipment market, valued at 279.22 billion USD in 2024, is projected to grow by 36% annually through 2030 [7], reflecting the technology's expanding influence across all sectors of human activity.

In education, AI algorithms and educational robots have become integral components of learning management systems, providing sophisticated support for diverse educational activities [8, 9, 10]. Recent advances in generative AI, particularly large language models like GPT-4, have accelerated this transformation, enabling unprecedented levels of personalization and adaptive learning [11, 12, 13]. Similarly, in scientific research, AI methodologies are revolutionizing hypothesis generation, experimental design, and data analysis, creating new paradigms for scientific discovery [14, 1].

This literature review critically examines the current state of AI integration in educational and scientific practice, synthesizing findings from international research conducted between 2018 and

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2025. We analyze the contributions of leading researchers while identifying persistent challenges and emerging opportunities in this rapidly evolving field.

2. Analysis of recent research and publications

2.1. International perspectives on AI in education

Among foreign researchers who have significantly contributed to understanding AI's role in education, several scholars have provided foundational insights that continue to shape the field.

Neil Selwyn's critical analysis of educational technologies has been particularly influential in examining both opportunities and risks. In "Should robots replace teachers? AI and the future of education" [15], Selwyn interrogates the fundamental assumptions underlying AI integration in education, arguing that while AI can enhance certain educational functions – assessment, personalization, administrative efficiency – it cannot replicate the essential human dimensions of teaching: emotional connection, pedagogical intuition, and ethical judgment. His recent work with colleagues on generative AI [16] examines the explosive growth of AI tools, highlighting critical ethical challenges including copyright infringement, algorithmic bias, and the spread of misinformation in educational contexts.

Rose Luckin's research provides a complementary perspective, focusing on the practical implementation of AI to enhance learning outcomes. Her seminal work "Machine Learning and Human Intelligence: The Future of Education in the 21st Century" [17] establishes a framework for understanding how AI can augment rather than replace human intelligence in educational settings. Luckin et al. [18] demonstrate that AI's greatest potential lies in its ability to personalize educational experiences, tailoring content, pacing, and assessment to individual learner needs. This personalization extends beyond simple adaptation; it encompasses the creation of individual learning trajectories that respond dynamically to cognitive abilities, learning styles, and emotional states.

The critical importance of ethical AI implementation emerges as a central theme across recent literature. Khosravi et al. [19] introduce the XAI-ED framework, addressing the unique requirements for explainability in educational contexts. Their work identifies six key aspects: stakeholder diversity, pedagogical benefits, explanation presentation methods, model transparency, human-centered design, and potential pitfalls. This framework has become essential for building trust in AI-powered educational systems.

Recent empirical studies have validated the effectiveness of AI-enhanced learning [20, 21]. Kestin et al. [22] report results from a randomized controlled trial demonstrating that students using AI tutors learn significantly more in less time compared to traditional active learning classes, while also reporting higher engagement and motivation. However, these benefits are not uniformly distributed. Matos et al. [23] systematic review of 45 studies reveals that while ChatGPT and similar tools show strong performance in theoretical knowledge delivery, challenges persist regarding data privacy, algorithmic bias, and the need for specialized educator training.

The paradigm shift in AI's educational role is comprehensively analyzed by Ouyang and Jiao [2], who identify three evolutionary paradigms: AI-directed (learner-as-recipient), AI-supported (learner-as-collaborator), and AI-empowered (learner-as-leader). This framework captures the field's trajectory toward greater learner agency and personalized, data-driven education.

2.2. AI in scientific research methodologies

The integration of AI into scientific research represents a fundamental transformation in how knowledge is generated and validated [24]. Wang et al. [1] provide a comprehensive overview of how AI augments and accelerates research through self-supervised learning, geometric deep learning, and generative methods. These technologies enable scientists to generate hypotheses, design experiments, and interpret complex datasets at unprecedented scales.

Particularly noteworthy is the development of automated research systems. Luo et al. [14] introduce BioResearcher, an end-to-end automated system for biomedical research that employs a modular multi-agent architecture. This system achieves an average execution success rate of 63.07% across previously unmet research objectives, demonstrating AI's potential to independently conduct scientific investigations. Similarly, Akujuobi et al. [25] present THiGER, a temporal graph-based approach for hypothesis generation that leverages active curriculum learning to predict future entity relationships in scientific literature.

The application of generative AI in scientific discovery has shown particular promise. Das [26] review advances in drug discovery and protein design, highlighting how variational autoencoders (VAEs), generative adversarial networks (GANs), and diffusion models enable inverse molecular design and de novo protein engineering. These methods have already produced AI-designed molecules that have progressed to clinical validation, marking a significant milestone in AI-driven scientific innovation.

2.3. Developments in Ukraine, Poland, and Eastern Europe

Ukrainian scientists have made significant contributions to understanding AI's educational applications within specific regional contexts. Lobanova et al. [27], Fadieieva [28], Riabko and Vakaliuk [29] explores the prospects for AI integration in Ukrainian education, analyzing successful implementations of personalized learning, automated assessment, and adaptive learning environments. The work of Kolomiets and Kushnir [30] addresses two fundamental aspects: AI's opportunities and threats in teacher training, and its impact on research organization and conduct. They emphasize that while AI has revolutionary potential for the scientific community, this transformation brings ethical and practical challenges that require careful navigation.

Androshchuk and Maluga [31] provide a comprehensive analysis of AI trends in Ukrainian higher education, examining both international and domestic experiences. Their research highlights the urgent need to rethink educational approaches, balancing AI's advantages with concerns about academic integrity and educational quality. Panukhnyk [32] offers a unique perspective on virtual reality as a newly organized social space that encourages systematic changes in educational processes and student research activities, arguing that AI serves as a modern pedagogical mechanism with important conceptual and methodological significance.

Polish researchers have contributed valuable insights into competency development and practical implementation strategies. Symela and Stępnikowski [33] analyze the workforce challenges associated with AI development in Poland, noting that up to 40% of working hours may be automated by 2030. They propose the "HUN" (Hybrid & Unconventional) competency development model to address technological unemployment through adaptive education. Recent studies by Kopczyński [34] examine AI integration in Polish universities, with particular attention to chatbot applications for student support and the ethical dimensions of personalized learning systems.

3. Emerging themes and critical issues

3.1. Explainable AI and trust in educational systems

The emergence of explainable AI (XAI) represents a critical development in educational technology. Liu et al. [35] demonstrate how combining SHAP and LIME methods provides both global feature importance and individual decision insights, essential for maintaining transparency in educational assessment. Furze et al. [36] report on implementing the AI Assessment Scale (AIAS), showing significant reductions in academic misconduct while enhancing student engagement with AI technology.

The importance of causability – users' ability to understand AI's cause-effect linkages – emerges as a key factor in building trust. Lünich and Keller [37] experimental study reveals that decision tree simplicity positively affects fairness perceptions through enhanced causability, though institutional trust moderates these relationships. This finding has profound implications for designing transparent machine learning models in educational settings.

3.2. Ethical frameworks and regulatory developments

The rapid deployment of AI in education has outpaced regulatory frameworks, creating urgent needs for governance structures. The European Union's AI Act, analyzed by Saarela et al. [38], introduces critical provisions for education, including prohibitions on emotion inference AI and requirements for transparency in high-stakes decision-making systems. This regulatory approach reflects growing consensus that AI in education must balance innovation with protection of student rights and educational values.

Ersoy [39] proposes a comprehensive framework for inclusive AI transformation in education, emphasizing data-driven diversity, ethical design principles, transparency, accountability, and continuous improvement. The framework addresses critical issues of bias and inequity that can be amplified by AI systems if not carefully managed. Marín et al. [40] empirical study of 890 students and 162 faculty members reveals widespread concerns about data privacy (51.2% of faculty) and system transparency (61.1% of faculty), highlighting the gap between AI capabilities and stakeholder trust.

The challenge of algorithmic bias receives particular attention in recent literature. Idowu [41] systematic review identifies common debiasing strategies including sample weight adjustment, fairness through unawareness, and adversarial learning. Significantly, most studies find no strict tradeoff between fairness and accuracy, suggesting that ethical AI implementation need not compromise educational effectiveness.

3.3. Generative AI and learning paradigms

The advent of generative AI, particularly large language models, has fundamentally altered educational possibilities [42, 43]. Valdivieso and González [44] mixed-methods study in El Salvador reveals how socioeconomic disparities affect access to and use of generative AI tools, with lower-income students primarily using smartphones and free tools while higher-income peers access premium features on laptops. This digital divide threatens to exacerbate existing educational inequalities unless addressed through institutional policies and support structures.

Tan et al. [45] examination of student perceptions regarding generative AI regulations reveals complex relationships between guideline understanding, compliance, and academic integrity. Their theory of planned behavior model shows that while understanding promotes compliance, perceived restrictiveness and increased AI experience can negatively impact honest declaration of AI use. This finding underscores the need for balanced regulatory approaches that promote responsible use without stifling innovation.

Multi-agent systems represent a particularly promising development. Vaccaro et al. [13] demonstrate how GPT-4-based frameworks can dynamically adapt science content for middle school students, with pilot studies showing increased preference for personalized texts. Hedi et al. [46] AIA-PAL framework employs LangGraph and CrewAI to provide real-time monitoring and specialized pedagogical support through collaborative agent networks, addressing limitations in current intelligent tutoring systems.

3.4. Challenges in implementation and equity

Despite technological advances, significant challenges persist in AI implementation. Gouveia et al. [47] systematic review identifies key barriers including lack of human interaction, need for teacher training, and algorithmic inaccuracies. The digital divide remains particularly acute in developing regions. Isotani et al. [48] propose "AIED Unplugged" – an approach to creating AI-based educational technologies that function without stable internet or advanced infrastructure. Their implementation in Brazil positively impacted over 500,000 students across 7,000 schools, demonstrating the feasibility of context-appropriate AI solutions.

Teacher preparation emerges as a critical factor. Mouta et al. [49] educational design research reveals that comprehensive professional development must address not only technical skills but also ethical considerations and pedagogical integration. Tenberga and Daniela [50] development of AI literacy self-assessment tools shows that while AI competencies overlap with digital skills in some areas, they form distinct categories requiring focused attention.

The intersection of AI with disability and special education presents both opportunities and challenges. Kohnke and Zaugg [51] demonstrate how AI can promote equity in STEM education for students with disabilities through personalized learning and improved accessibility. Farhah et al. [52] ALGA-Ed framework leverages generative AI to create customized multimodal content for diverse disability profiles, showing improvements in participation, retention, and learning outcomes.

4. Key unresolved issues requiring further investigation

Our analysis reveals several critical areas requiring sustained research attention:

1. *Ethical dimensions and accountability*: How can we develop algorithmic accountability mechanisms that prevent bias while maintaining educational effectiveness? The literature reveals persistent tensions between automated decision-making and human oversight. Who bears responsibility for pedagogical errors made by AI systems? How do we balance efficiency gains with preservation of human agency in education?
2. *Teacher autonomy and professional identity*: The active implementation of AI fundamentally alters teachers' roles, yet research inadequately addresses how educators navigate this transformation. How does AI affect teachers' professional autonomy in assessment, curriculum design, and pedagogical decision-making? What new competencies must teachers develop to effectively collaborate with AI systems while maintaining their unique human contributions?
3. *Long-term cognitive and social development*: Current research predominantly examines short-term learning outcomes, leaving critical questions about AI's long-term impacts unanswered. Can partial replacement of human interaction with AI agents affect students' development of empathy, critical thinking, and communication skills? How does AI-mediated learning influence students' metacognitive abilities and self-regulated learning strategies?
4. *Global equity and access*: The digital divide threatens to transform AI from an equalizing force into a mechanism for perpetuating inequality. How can we ensure equitable access to AI-enhanced education across socioeconomic, geographic, and cultural boundaries? What adaptations are necessary for AI systems to function effectively in resource-constrained environments?
5. *Academic integrity in the AI era*: Generative AI fundamentally challenges traditional concepts of academic integrity. How do we redefine plagiarism and original work when AI can generate sophisticated academic content? Should assessment methods evolve to embrace AI collaboration rather than prohibit it? How do we balance the benefits of AI-assisted learning with maintaining authentic skill development?
6. *Methodological rigor in educational AI research*: What metrics accurately capture AI's multifaceted impact on education? How can we conduct rigorous comparative studies when AI systems evolve rapidly? What longitudinal research designs can assess AI's cumulative effects on educational and career trajectories?
7. *Epistemological implications for scientific knowledge*: AI's role in scientific research raises fundamental questions about the nature of knowledge creation. How does AI-generated hypothesis formation affect scientific epistemology? What validation frameworks ensure AI-derived scientific conclusions remain transparent and reproducible? How do we maintain scientific rigor when AI systems operate as "black boxes"?

5. Future directions and recommendations

Drawing on the comprehensive analysis, we identify a coordinated agenda of research priorities alongside practical steps for implementation.

Research should first focus on longitudinal impact, with multi-year cohort studies that track students' cognitive, social, and emotional development across different AI-enhanced learning conditions. These studies must extend beyond conventional achievement metrics to capture creativity, critical thinking, and interpersonal skills, and they should use mixed methods to illuminate mechanisms of change and distributional effects across learner subgroups.

A second priority is context-responsive AI development. Applications should be designed and evaluated for diverse educational settings, particularly in low-resource environments. This includes offline-capable tools that do not depend on constant connectivity and systems that align with local pedagogical traditions while responsibly leveraging technological capabilities.

Third, research should examine hybrid human–AI pedagogical models to determine optimal divisions of labor. Work is needed to identify which instructional functions are best supported or automated by AI and which require distinctly human expertise, as well as to assess impacts on teaching practice, student engagement, and learning equity.

Finally, the field should move from ethical principles to implementation. This entails developing usable instruments for detecting and mitigating algorithmic bias, creating accountability mechanisms and governance protocols appropriate to education systems, and evaluating the feasibility and effectiveness of these approaches in real settings.

Translating these priorities into practice requires action by multiple stakeholders. Educational institutions should introduce comprehensive AI literacy for students, teachers, administrators, and parents; establish ethics committees to oversee adoption and respond to emerging issues; promulgate transparent policies that balance innovation with academic integrity; and invest in infrastructure that ensures equitable access to AI tools for all learners.

Policymakers should develop adaptive regulatory frameworks that can evolve with technological change; mandate auditing and transparency for educational AI systems; fund research on long-term impacts and equity implications; and support professional development to prepare educators for AI-enhanced teaching.

Technology developers should prioritize explainability and transparency in system design; engage educators and students as co-designers rather than passive end users; build culturally responsive systems that respect diverse learning traditions; and implement robust privacy protections rooted in data minimization.

Researchers should adopt interdisciplinary approaches that integrate technical, pedagogical, and ethical perspectives; create standardized metrics for assessing AI's educational impact; conduct comparative studies across cultural and socioeconomic contexts; and investigate how AI interacts with other emerging technologies in education. Together, these steps chart a practical path toward effective, equitable, and accountable use of AI in learning environments.

6. Conclusion

The integration of artificial intelligence into educational and scientific practice represents both unprecedented opportunity and significant challenge. Our comprehensive review reveals a field characterized by rapid technological innovation, evolving pedagogical paradigms, and persistent ethical concerns. While AI demonstrates clear potential to personalize learning, accelerate scientific discovery, and democratize access to knowledge, its implementation raises fundamental questions about human agency, educational equity, and the nature of knowledge itself.

The literature indicates a clear trajectory from AI as a supplementary tool toward AI as an integral partner in education and research. This evolution demands not passive acceptance but active engagement from all stakeholders to shape AI's role in ways that enhance rather than diminish human potential. The shift from AI-directed to AI-empowered learning paradigms reflects growing recognition that technology's value lies not in replacing human capabilities but in augmenting them.

Critical challenges persist, particularly regarding algorithmic bias, data privacy, and the digital divide. These are not merely technical problems but fundamental issues of educational justice that require sustained attention from researchers, practitioners, and policymakers. The development of explainable AI and ethical frameworks represents progress, but significant gaps remain between theoretical frameworks and practical implementation.

Looking forward, the field requires more nuanced understanding of AI's long-term impacts on cognitive and social development, more robust methodologies for assessing educational outcomes, and more inclusive approaches to technology deployment. The experiences of early adopters, particularly in resource-constrained environments, provide valuable lessons for scaling AI-enhanced education globally.

Ultimately, the question is not whether AI will transform education and science – that transformation is already underway – but how we can guide this transformation to serve humanity's highest aspirations. This requires maintaining a critical perspective that neither uncritically embraces technological solutions nor reflexively resists innovation. Instead, we must cultivate what might be called "critical technological wisdom" – the ability to discern when, how, and why to deploy AI in service of authentic human development.

The path forward demands unprecedented collaboration across disciplines, cultures, and sectors. Computer scientists must work with educators, ethicists with engineers, and policymakers with practitioners. Only through such collaboration can we realize AI's potential while safeguarding the essentially human dimensions of learning and discovery that no algorithm can replace.

As we advance into an AI-enhanced future, we must remember that education's ultimate purpose transcends efficiency and optimization. It encompasses the cultivation of wisdom, creativity, empathy, and ethical reasoning – qualities that remain fundamentally human. The challenge and opportunity before us is to harness AI's power in ways that amplify these human qualities rather than diminish them, creating educational and scientific ecosystems that are both more powerful and more humane.

Declaration on Generative AI

The authors used Scopus AI to find the additional references, and the gpt-5-high-new-system-prompt model to polish sentences.

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A case study of applying Grammarly for mastering pre-service teachers' writing skills

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Abstract

Artificial intelligence constitutes an integral component in the organization of a digital language learning environment. Grammarly offers significant advantages for pre-service teachers, particularly in improving their academic writing skills. The primary objective of this study was to analyse the influence of Grammarly on mastering the English academic writing skills of University students majoring in English. In the study, the pre-interview and post-interview were used as instruments to collect data of the writing problems in grammar, vocabulary, and spelling. The data was collected from 50 students of Pavlo Tychyna Uman State Pedagogical University (Uman, Ukraine) in the period from October 2024 to April 2025. The important issues of the study were pragmatic components of writing and language accuracy. The aforementioned issues were designed to develop criteria for writing a paper. The key criteria for the pragmatic components of writing include recognizing the differences between writing in English and one's native language, utilizing Grammarly for relevant support, considering the impact of writing on the target audience, incorporating extralinguistic elements, ensuring originality without plagiarism, and maintaining textual coherence and cohesion. The essential criteria for language accuracy include using an appropriate register, maintaining correct grammar, and selecting precise vocabulary. The findings indicate that students might use additional resources, such as Grammarly, to assist them with writing tasks. The findings of the study can be used by higher education institutions that train English future teachers in order to develop writing skills of pre-service teachers and introduce Grammarly into the educational process. Grammarly is recommended as it enhances university students' writing skills, particularly in academic writing courses. Future research could involve comparative analyses of grammar and vocabulary accuracy using Grammarly within the context of English academic writing.

Keywords

pre-service teachers, EFL, AWE system, artificial intelligence, Grammarly, writing skills

1. Introduction

With the development of international contacts, Ukraine's pursuit of joining the European Union, and the growing influence of digital technologies in education, pre-service teachers are increasingly required to acquire effective writing skills. Digital learning tools play a crucial role in this preparation, particularly in fostering English language communicative competency with a focus on writing skills.

In recent years Ukrainian education has faced significant disruptions due to the global pandemic and ongoing military conflicts [1, 2, 3, 4, 5, 6, 7, 8], however, the advancement of education through innovation and digitalization is keeping pace with modern times [9, 10, 11, 12, 13]. Higher education institutions are responsible for delivering quality education that prepares pre-service educators to compete effectively in the global job market.

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Ukrainian students can be prepared with the knowledge and skills required for advanced academic writing, including descriptive, analytical, argumentative, and critical writing. In all these cases in higher education, Grammarly is an important resource in the digital space that enhances professional competency of pre-service teachers [14, 15, 16].

Writing is a fundamental skill for English learners. It is both a highly rewarding and a particularly challenging skill to master. Today, digitalization and innovation have been leveraged to enhance the quality of writing. Although challenging to master, academic writing is an essential university skill that is rigorously assessed [17, 18, 19]. Writing, as a linguistic activity and a key objective of pre-service teachers in mastering their skills, is enhanced through the integration of digital tools, particularly Grammarly that aims to assist and support students, whether beginners or experts, in identifying and correcting writing errors at the level of spelling, grammar, punctuation, vocabulary, sentence structure, style, and engagement.

The objective of this research is to analyse the influence of Grammarly on mastering the English academic writing skills of University students majoring in English.

Consequently, this study explores how pre-service teachers utilize Grammarly prompts and their perspectives on learning English through Grammarly. Accordingly, the study aimed to answer the following questions:

1. How can pre-service teachers use Grammarly prompts to master their academic writing?
2. What problematic issues are associated with the employment of the application, and how can they be addressed?
3. What recommendations can be developed for educators to effectively use Grammarly in the learning process?

2. Literature review

Many researchers [20, 21, 22] rely on Grammarly to address communication challenges. By integrating Grammarly into their workflows, educators and students can improve customer-facing content, strengthen cross-functional collaboration, and uphold a high standard of communication on a larger scale. According to recent research [23, 24], improving writing skills through automated writing assistants like ChatGPT, YouChat, Perplexity, Gemini, Copilot and others help students address deficiencies in spelling, grammar, and style. These tools are widely used across the globe. However, while digital tools can greatly aid learning, there is also the risk of overreliance on artificial intelligence (AI), which might lead to the loss of human understanding in writing [25, 26, 27]. It is crucial to emphasize that humanity faces a risk from robo-writers, as AI can generate human-like text without true comprehension or accountability for its content.

Scientists argue that online resources facilitate the creative application of digital technologies, help identify the needs of both teachers and students, provide technological solutions, resolve technical issues, and pinpoint gaps in digital competency, consequently, preparing pre-service teachers must be done with digital technologies [28, 29]. Various applications and online platforms offer innovative digital tools that can help students moderate mediation model of writing self-efficacy [30, 31]. Among the advantages of online resources Williams and Beam [32, p. 227] found that "the use of technology motivated student engagement and participation in writing assignments and increased social interaction and peer collaboration". The authors emphasized the importance of educators' digital competency: "Relevant, high-quality teacher professional development on pedagogical uses of technology are urgently needed in order to promote technology-mediated writing instruction and build students' 21st century literacy skills" [32, p. 227]. Nguyen [33] examined digital tools to promote academic writing skills. His findings highlight the significance of combining digital tools with focused instructional support to tackle both small-scale and large-scale writing challenges.

The experience of using other digital tools such as ChatGPT has demonstrated its potential to support English language learning among older individuals, who are often perceived as facing technological or linguistic challenges. Sanmuang et al. [24] emphasized that, with appropriate tools and methods, these learners can effectively engage with ChatGPT, showcasing how diverse age groups and backgrounds can overcome learning obstacles. The success of such educational initiatives relies heavily on using the right approach and resources.

Recent research presents varied views on Grammarly in English learning. First of all, the researchers try to find advantages, weaknesses, and challenges of Grammarly application. Perdana et al. [34, p. 128] appreciated its role in improving academic writing and highlighted "the effectiveness in providing corrections and other checks to accommodate many linguistic issues in writing academic standards and the outside academic world". Guo et al. [35] recognized the utility of AI in corrective feedback but despite its widespread use in EFL classrooms and numerous benefits, Grammarly, an automated writing evaluation (AWE) tool, remains underrepresented in AWCF studies. Thi et al. [36] noted teachers' satisfaction with the AI writing tools that positively improved their students' writing quality, particularly enhancing the quality of their content and organization. Rizky and Didik [37] found that Grammarly is an effective tool for teaching English writing skills and can complement traditional writing instruction. The study gathered both quantitative and qualitative data, incorporating pre- and post-test evaluations of writing skills along with surveys and interviews to assess participants' perceptions of Grammarly. Investigating the effects of using Grammarly in EFL writing, Ebadi et al. [38] recommended EFL teachers to incorporate online grammar checkers into their writing courses as they are writing assistant tools to detect and remove English as a foreign language (EFL) learners' grammatical errors. Koltovskaia's [39] findings indicated that students exhibited varying levels of engagement with digital checkers. One student demonstrated higher cognitive engagement by questioning the feedback but made only moderate revisions due to limited verification of its accuracy. In contrast, the other student's overreliance on digital checkers reflected lower cognitive engagement, leading to unquestioned acceptance of the feedback. However, this also resulted in moderate revisions to their drafts. Koltovskaia [40] pointed out that Grammarly is a complement to teacher feedback but should not be used to replace teacher feedback.

Numerous studies have been conducted on Grammarly in EFL writing, including confidence, help-seeking behavior, and user perceptions of Grammarly in higher education [41], and meta-analysis on the effectiveness of automated writing evaluation on writing quality [42].

However, despite the many advantages of using Grammarly, Dizon and Gayed [43] do not recommend it as a substitute for teacher feedback. The researchers believe that Grammarly should complement teacher feedback, enabling instructors to concentrate on higher-level writing concerns while the AWE system addresses lower-level errors [43].

3. Research methods

The research took place between October 2024 and April 2025. It employed a range of methods depending on its stage. Thus, at the initial one – pre-intervention – we applied the interview with the 15 members of the focal student group and 5 teachers of English from the Faculty of Foreign Languages, Pavlo Tychyna Uman State Pedagogical University (Uman, Ukraine). Moreover, 50 students' written papers were analysed.

At the intervention stage, we carried out an experiment with the focal group and their teachers of English, who were introduced 'Grammarly' (business version) as a part of the joint project of the Ministry of Education and Science of Ukraine and the corporation 'Grammarly' for higher educational establishments in Ukraine. Respectively, Pavlo Tychyna Uman State Pedagogical University got 50 licenced places from October 2024 till October 2026.

At the post-intervention stage, the students' writing achievements were scrutinised, and the research participants were interviewed once again.

4. Results and discussion

At the initial stage of the research, the students were interviewed about their writing competency. They were addressed with questions concerning their attitude to writing, the difficulties they experienced, and whether they had their own writing strategy. The student's understanding of writing was checked with the use of the following criteria for writing (table 1).

Table 1
Criteria for writing a paper.

Pragmatic components of writing	1) *Understanding the rhetorical differences between writing in English and Ukrainian*
	2) *Paper's idea revealed with relevant support*
	3) *Effect of writing on the targeted audience*
	4) *The paper's purpose achieved*
	5) *Extralinguistic means adequately employed if necessary*
	6) *Plagiarism avoided*
	7) *Coherence created*
	8) *Cohesion achieved*
Language accuracy	a) *Relevant register & style*
	b) *Relevant grammar*
	c) *Relevant vocabulary*
	d) *Range of grammar and vocabulary use*

The interview results demonstrate that 90% of students associate their writing problems only with relevant language use while writing (e.g. grammar, correct vocabulary, and spelling). Still, the analysis of the students' papers reveals that they intuitively try to achieve some of the pragmatic goals and language accuracy as well. Their vision of the writing strategy is also quite intuitive and vague. Only 2 out of 15 claimed writing to be their favourite activity (figure 1).

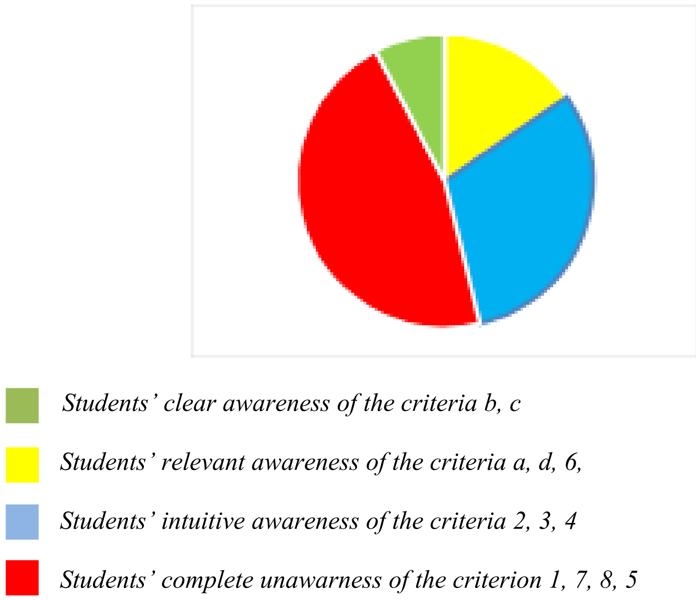

Figure 1: Levels of students' awareness of the criteria for writing.

At the intervention stage, the focal group of students and teaching staff were introduced to the business version of Grammarly and explained the range of tools they can employ to improve their writing including the generative AI. To address the research questions, we followed the group's Grammarly use to advance their pragmatic competency while writing as well as language accuracy.

From the perspective of the pragmatic approach to writing, only 15% of students employed Grammarly's AI possibilities to brainstorm the ideas for writing and organise them logically and subsequently into a structured form. The application helped the students define their audience, for instance, knowledgeable, still it could hardly help them understand the potential audience's real needs and interests. So, while discussing this issue during the English classes, the students expressed their opinions about interviewing targeted readers or analyzing their reactions, comments and feedback on social media concerning a definite topic.

Extralinguistic means like appropriate photos, font, colour of the text and others were not the point to be suggested by Grammarly. In this respect, the students and teachers relied on their knowledge from the courses "Creative and Academic Writing" and "Basics of English Writing", their personal experience and the suggestions of other Art Generating AI and ChatGPT.

On the other hand, Grammarly Premium's plagiarism checker could help the students and teachers to catch sentences and paragraphs that may need a citation. Still, this function was rarely addressed by the students (less than 12% of cases). Instead, their instructors exploited it to check how the students follow the ethical norms.

The largest references to Grammarly were associated with improving the students' language accuracy in terms of grammar and vocabulary use, appropriate register and tone for writing. In the period between October 2024 and April 2025, the students accepted from 68 to 72.1% of suggestions provided by Grammarly (figure 2).

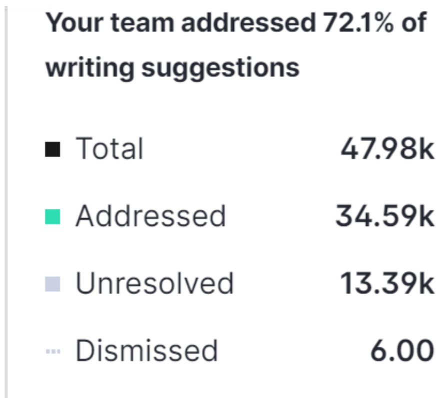

Figure 2: Students' reactions to Grammarly's suggestions (a screenshot from the application).

As the screenshot given above (figure 2) demonstrates, a small amount of Grammarly suggestions were dismissed. To clarify this point the students were questioned, whether they checked what the application suggested or accepted it without deep consideration. The students expressed their reliance on Grammarly in this matter without thorough examination of the provided suggestions. We consider this tendency to be quite threatening for the students' learning process and a significant disadvantage of application's use. As Grammarly operates a definite set of grammar and vocabulary use patterns, in some cases taking its recommendations for granted can lower the level of students' self-expression and reduce the variety and richness of the language tools, which students master in their courses of English-related subjects. Still, 80% of students and all the teachers found the application to be quite useful for mastering core grammar and vocabulary.

Overall, the benefits, risks, and problematic issues associated with Grammarly use in the English learning process can be generalized as follows (table 2).

At the post-intervention stage, the participants of the experiment were interviewed once again concerning their impressions of the application employment in the learning process. In general, they provided positive feedback although there were some recommendations. Firstly, to address the problematic issues associated with Grammarly use, teachers are recommended to explain their students the scope of its effectiveness with the necessity to analyse and scrutinise its suggestions and develop more trust in personal knowledge and competencies in English. Secondly, it should be noted that

Table 2
Advantages and challenges of grammarly use.

Advantages	Challenges
Interaction	Free access limitation
Time saving	Contextual limitation
Wide availability	Multilinguistic limitation
Error detection	Online-enabled dependence
Style suggestion	Failure to understand idioms or other stylistic figures
Word choice improvement	Misunderstanding of author's individual style
Relatively correct English use prompts	Weekly comparisons with the performance of other team members (ethical issue)

Grammarly can partially help master the pragmatic components of writing. Thus, it is highly advised to practice them in the courses of English-related subjects and writing-related ones.

The analysis of the students' works demonstrated enhanced levels of productivity, grammar and vocabulary use with the tendency to reduce the Grammarly's recommendations from month to month, which proves that the application helped the students to strengthen their writing competency in terms of language accuracy (table 3).

Table 3
The influence of Grammarly on students' writing between October 2024 and April 2025.

Months	Students' productivity (%)	Grammar use recommendations (%)	Vocabulary use recommendations (%)
October 2024	25.5	42.3	39.5
November 2024	27.6	41.2	37.5
December 2024	28.5	39.5	34.5
January 2025	30.1	38.5	32.5
February 2025	32.5	35.7	30.2
March 2025	33.8	36.0	29.8
April 2025	35.5	33.5	28.1

Thus, it is obvious from the table that Grammarly has positively influenced the dynamics of students' language accuracy development as they required less application's help while writing their academic pieces. During the post-intervention interviews, the learners claimed that their confidence in writing rose significantly, especially when they realized that Grammarly is only an assistant which requires their own inclusion in the process of mastering their language skills.

5. Conclusions and perspectives for further research

This study demonstrates how Grammarly can support English language learning for pre-service teachers who are often perceived as facing digital and writing difficulties. It illustrates that, with appropriate tools and strategies, the future English teachers can effectively engage the effective writing with Grammarly, showcasing how they overcome the barriers in productivity, grammar, and vocabulary use. The research underscores the importance to understand the benefits, limitations, and challenges associated with using Grammarly as an online, cloud-based writing assistant that checks writing. Pre-service teachers should receive training in technology, Internet literacy, and English proficiency to effectively utilize Grammarly prompts.

In response to the first research question, participants viewed Grammarly positively for its impact on their academic writing. They appreciated the ability to interact with AI, save time, and access a wide range of vocabulary and word choices. Additionally, they trusted Grammarly's suggestions and were comfortable adopting its writing style, reducing their concerns about making mistakes. Regarding the second research question on problematic issues, participants indicated that while they aimed to achieve certain pragmatic goals and maintain language accuracy, their approach to writing strategies remained largely intuitive and unclear. In response to the third research question there were developed some recommendations to effectively employ Grammarly in the learning process. First of all, it is highly advised to address the problematic issues associated with Grammarly use, meaning the instructors should explain their students the scope of its effectiveness with the necessity to analyse its suggestions and develop more trust in personal knowledge and competencies in English. Thus, building a relevant level of students' responsibility and accountability for their writing can be achieved. Secondly, it should be noted that Grammarly can partially help master the pragmatic components of writing. Thus, it is preferable to practice them in the courses of English-related subjects, especially writing-related ones. Apart from that, special workshops and seminars can be conducted to focus on mastering specific pragmatic soft skills.

This study demonstrates that, with appropriate approach to Grammarly use, pre-service teachers can effectively enhance their writing skills. It underscores the importance of the right tools for the success of such educational initiatives. Future research could involve comparative analyses of grammar and vocabulary accuracy using Grammarly within the context of English academic writing.

Declaration on Generative AI

The authors have not employed any generative AI tools.

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Issues in assessing and certifying the digital competence of educators

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Abstract
The article discusses the concept of "digital competence" and methods for determining its level of formation. The authors analyze the connection of this concept with others, such as "computer literacy", "information literacy", and "information culture". Special attention is given to the model of information culture proposed by M. I. Zhaldak, Yu. S. Ramsky and M. V. Rafalska. The article also examines various models of digital competences, such as DigComp, and their evolution from 2013 to 2022. It describes the main changes in these models, including the addition of new competencies and adaptation to modern technologies and social needs. The authors analyze methods for measuring digital competence, including self-assessment, analysis of digital tasks, and secondary data collection. Special attention is given to the Ukrainian experience of assessing teachers' digital competences, particularly through the certification system implemented by the Ministry of Education and Science of Ukraine. The conclusions emphasize the need for further development of the certification system for educational workers, taking into account European experience and the introduction of competency tasks using computer technology.

Keywords
digital competence, educators, assessment methods, certification, DigComp, information culture, teacher professional standard, Ukraine, self-assessment, competency tasks

1. Introduction

When considering the concept of "digital competence" and the methods for determining its level of formation, it is necessary to examine the connections of this concept with other concepts that have been actively used by scientists from various countries. These concepts include "computer literacy", "information literacy", "information and communication literacy", "information culture", "information and communication culture", and others. One of the first interpretations of the concept of "information culture" in Ukraine was given by Zhaldak [1, 2, 3]. In his doctoral dissertation, he noted that information culture is one of the components of the general culture of a person, and information culture itself should be considered as a certain level of organization of information processes, the degree of satisfaction of people's needs in information communication, and the level of efficiency in creating, collecting, processing, transmitting, and using information that ensures the formation of a holistic picture of the world and the ability to predict the consequences of decisions made [1].

The connection between these concepts is more fully considered in the model of information culture proposed by Zhaldak et al. [4]. In this model, the more general term "informatics culture" includes "informatics competencies", "information reflection", and others (figure 1).

Ramsky [5] provided a more detailed description of the requirements of a teacher in the era of computerization of education in his work.

A detailed comparative analysis of the interpretation of the concepts of "information culture", "information literacy", "information competencies" is presented in the work of Havrilova and Topolnik [6]. An analysis of the views of foreign and Ukrainian scientists on the content component of the concept of

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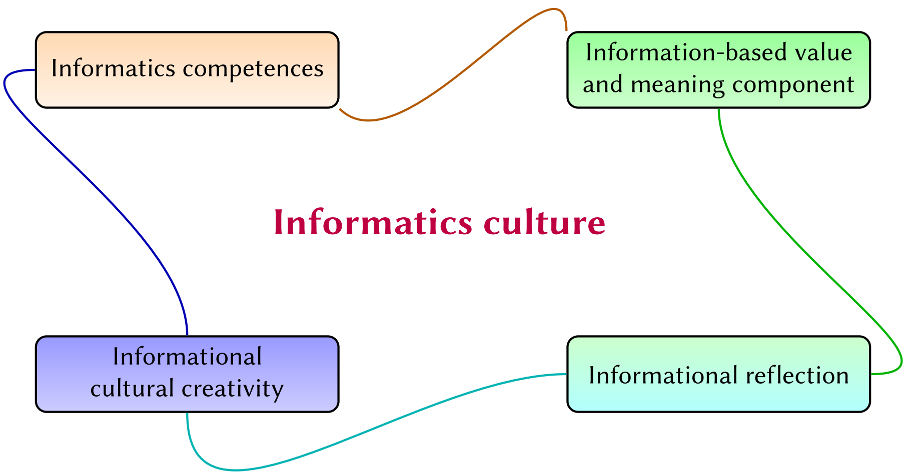

Figure 1: Model of informatics culture by Zhaldak et al. [4].

"information competence" in relation to the teaching profession is presented in the article by Henseruk [7].

As Ala-Mutka [8] notes, learning is necessary to form digital competence. Simply increasing the amount of time spent working with digital devices does not develop digital competence, does not provide the employee with inclusion in the modern system of digital relations, and does not develop him as a professional and promising specialist [9, 10, 11].

Therefore, actions are needed to encourage the development of digital competence for all citizens, regardless of their age, profession, or current use of ICT.

2. Theoretical background

The intensive development of information technologies and the increasing demands on workers in terms of professional-oriented and everyday use of these technologies have led to the emergence of a number of models in the first decades of the 21st century that describe the system of knowledge and skills that current and future specialists in various fields should possess. Such models include Digital Transformation: A Framework for ICT Literacy [12], SCONUL Seven Pillars of Information Literacy [13], Framework for Basic Skills: Digital Skills [14], digi.komp - Digital Competences Framework for Austria [15], International Computer and Information Literacy Study: Assessment Framework [16]. The analysis of these models was carried out by Strutynska [17].

In 2006, the Council of the European Union defined digital competence as one of the eight key competences for sustainable development of society [18]. In 2018, the Council of Europe reviewed the list and definitions of key competencies, but digital competence remained among key competencies and its role was strengthened [19].

As a result of the work of EU structures in the direction of digital education of the population, one of the most well-known models of digital competences emerged, DigComp.

DigComp (Digital Competence Framework for Citizens) is a European framework for digital competences that was developed to define the content of knowledge and skills, the extent of mastery of which indicates the level of formation of digital competences for active advancement in various spheres of modern society.

By using this framework and comparing the skills described in it with the actual skills of a particular person, it is possible not only to diagnose the current level of digital competences but also to plan further learning directions and form an individual educational trajectory for a person in the field of digital technologies.

Since its first release in 2013, DigComp has undergone several updates, including versions 2.0 [20], 2.1 [21], and 2.2 [22]. The most significant changes occurred during the transition from the first model of 2013 to the DigComp 2.0 model of 2016. Figure 2 schematically presents the main changes in the updated version of DigComp.

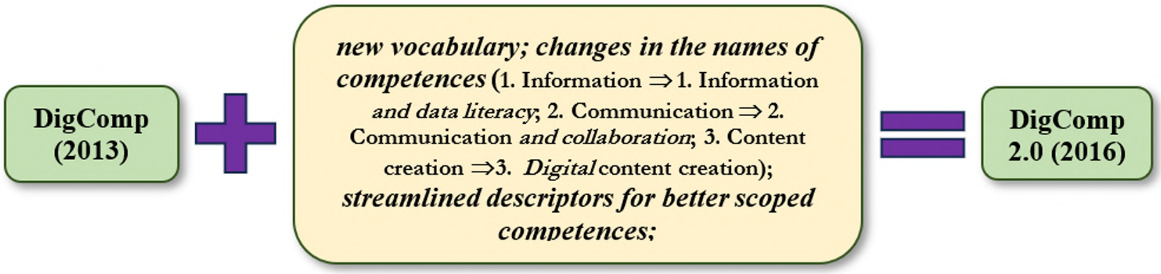

Figure 2: Schematic of changes between DigComp and DigComp 2.0.

The latest version to date, DigComp 2.2, was released in 2020 and underwent certain changes in 2022 [22]. It emphasizes sustainable development and social aspects (expanded role of digital competences in addressing social issues) and includes an improved structure to ensure usability and adaptation in various contexts (education, labor market, etc.). More attention is given to ethics, digital rights, and the use of digital technologies in various social and economic conditions. The competence framework has become more adaptable to various digital changes and different sectors.

The next version – DigComp 3.0 – is to be published by the end of 2025 and should introduce the following changes [23]:

- include learning objectives and learning outcomes for all 21 DigComp specific competences at the four macro proficiency levels;
- further incorporate recent and emerging trends and priorities of the digital world;
- be accompanied by information to support applications of the framework for a variety of purposes.

Thus, each new version of DigComp has become clearer, more adapted to modern technologies and the needs of citizens, aiming to anticipate and meet the challenges of the digital era. As noted by Vuorikari et al. [20], the DigComp framework is a universal tool and can be used for various purposes. The developers of DigComp envisioned its use from the very beginning for:

- defining strategies and ways to develop digital competence of citizens;
- planning (creating educational programs) training, the result of which will be the formation of digital competences of different segments of the population in various fields;
- assessing the levels of digital competence formation and certification (attestation) of managers, employees, and participants in educational processes at different levels.

The stakeholders interested in using DigComp include policymakers, educational and employment authorities at the national and regional levels, public and private educational institutions, and other organizations that provide educational services, among others.

Various programs for diagnosing the formation of digital competences and creating individual or group plans for improving (forming) digital competences have been developed based on DigComp. As noted by Strutynska [17], models or structures of digital competences (information and communication competences) have been developed and continue to be developed to determine the level of formation of digital competences of citizens and the ways to form them. Strutynska [17] lists over 20 models (structures) of digital competences, mostly developed in European countries and by the European Union.

An example of such services is the Digital Competence Wheel website [24], where developers offer to conduct self-assessment of digital skills proficiency, and subsequently organize training in those skills that are found to be underdeveloped. The authors position their program as based on the DigComp project. The result of the self-assessment of one of the authors is presented in figure 3.

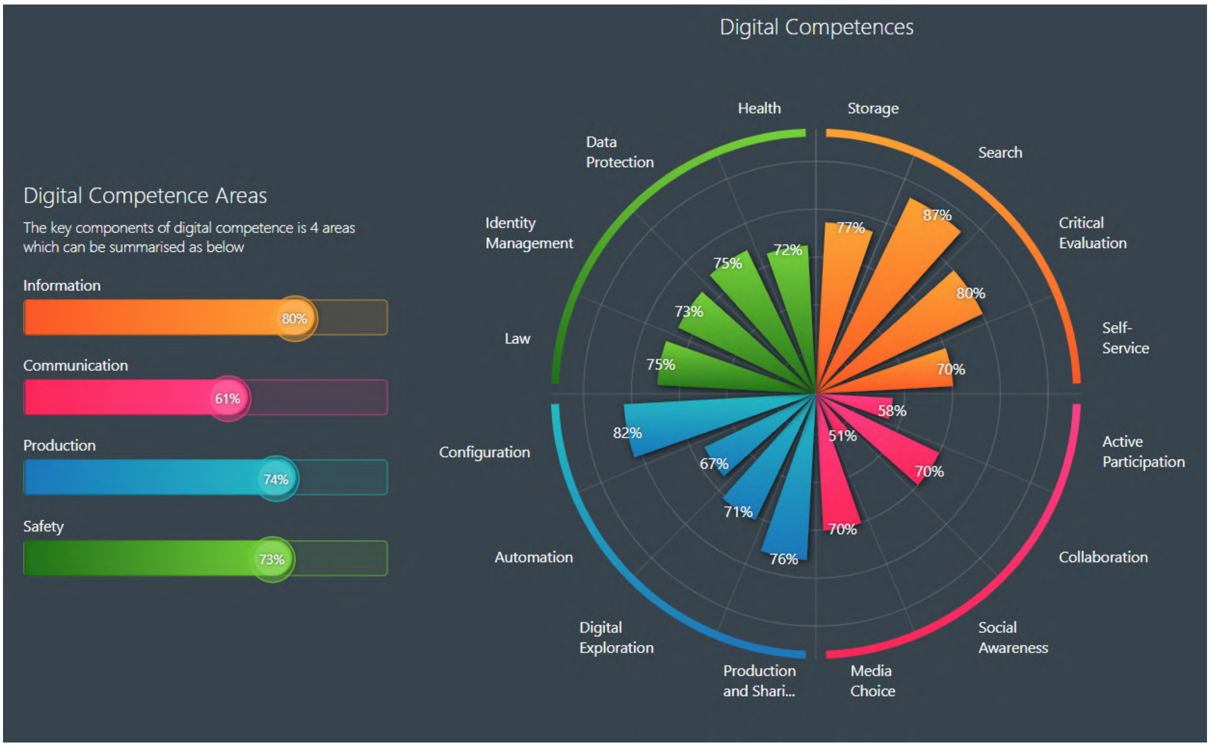

Figure 3: Self-assessment result on the Digital Competence Wheel service.

A similar scheme is used by the Jisc service [25]. Using the Discovery tool, an assessment of digital competences formation is carried out, followed by an individualized program for their improvement.

One of the ideologists of DigComp, Kirsti Ala-Mutka, policy officer at the European Commission, emphasized even before the implementation of DigComp [8] that during the development of systems for assessing the level of digital competences formation, three main measurement methods are mostly used with different forms of data collection for evaluation:

- ***User questionnaires*** – involve obtaining data from the users themselves by filling out written questionnaires or various online forms. Typically, these questionnaires include self-assessment of certain skills. Figure 4 shows an example of one of the questions in the Digital Competence Wheel self-assessment questionnaire. In this questionnaire, respondents are asked to rate a specific skill on a scale from “To a very small degree” to “To a very large extent”. Experts note that self-assessment cannot provide fully objective results [26]. Different categories of citizens, depending on age, social status, and familiarity with the content of the question, tend to overestimate or underestimate their self-assessment.
- ***Analysis of digital tasks*** – this method involves performing certain tasks that require the application of specific knowledge and skills in digital technologies. Examples of such tasks are competency tasks described in [27]. Using this method, we can obtain the most objective results and differentiate competences by levels defined in DigComp 2.2. However, this method is associated with significant time costs for checking completed tasks and requires high qualification from those who will be checking these tasks, especially when tasks involve variability or ambiguity in solutions. Additionally, quality control of completed competency tasks cannot always be automated, and under certain conditions, measures are needed to ensure the independence of task performance. Ala-Mutka [8] points out that there are no examples of European-level application

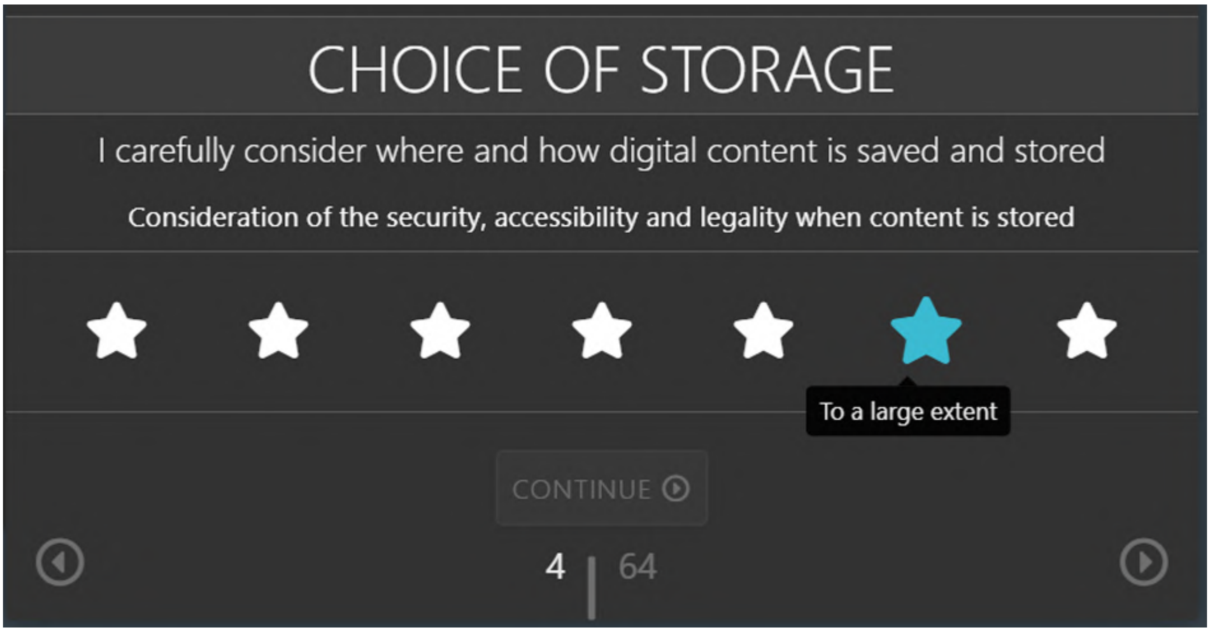

Figure 4: One of the survey questions in the Digital Competence Wheel.

of this type of measurement and evaluation. Perhaps such integrated measurements are indeed not carried out, but we have examples of effective commercial application of this method. Both Microsoft [28] and Cisco [29] practice certification of varying levels of complexity for specialists planning to work with specific software.

- ***Secondary data gathering and analysis*** – generally involves a longer period of data collection from various sources: analysis of regulatory documents governing the use of digital technologies in a particular enterprise or organization, descriptions of professional qualification requirements for employees, participants in educational processes, lists and quality of software, online services, etc. As an example of this method's application, Ala-Mutka [8] cites a study for the European Commission on media literacy conducted in 2009 by 21 [30].

3. Results

In Ukraine, for measuring and evaluating, including the parameters of digital competence, user questionnaires are most commonly used. The use of this method can be tracked on the Diia portal [31], as well as in survey materials regarding educators' readiness to use online tools and resources to ensure remote learning for students, determining the educational resources, electronic learning tools most in demand among teachers, and identifying their level of digital competence [32].

In pursuing the research objective – determining the tools and means for measuring and evaluating the digital competences of teachers in secondary educational institutions of Ukraine – we focused on the requirements for digital competence described in the Professional Standard "Teacher of a General Secondary Education Institution" [33]. The standard stipulates that to fulfill the main labor function A. Teaching subjects (integrated courses) to students, the teacher should have formed Information and Digital Competence (code AZ), which includes three competences:

A3.1. The ability to navigate the information space, search for and critically evaluate information, and operate with it in professional activities.

A3.2. The ability to effectively use existing and create (if necessary) new electronic (digital) resources.

A3.3. The ability to use digital technologies in the educational process.

For each of these competences, a list of knowledge, skills, and abilities, types of communications, as well as requirements for responsibility and autonomy, are defined.

The compliance of future educators with the requirements of the Professional Standard should be determined by higher education institutions during the final certification. The issue of the content of the final certification and methods of its implementation was not the aim of this research.

To analyze the effectiveness of measuring and evaluating the levels of digital competence formation among teachers working in educational institutions, we selected the teacher certification system, which has been implemented for several years by the Ministry of Education and Science of Ukraine (MESU) based on the Ukrainian Center for Educational Quality Assessment [34], as well as the digital competence certification system for pedagogical workers on the Diia portal [31].

We investigated the effectiveness of the measurement and evaluation system for digital competence of teachers by the Ukrainian Center for Educational Quality Assessment based on the materials of the second volume of the Report on Independent Testing of Professional Knowledge and Skills of Pedagogical Workers [35]. We analyzed the results of the certification tests of primary school teachers, teachers of Ukrainian philology, mathematics, and social studies. According to the certification program, five test tasks (subsection of the program Informatics Education and Digital Educational Environment) were provided to measure and evaluate the levels of digital competence formation among teachers, with an additional two tasks on digital competence placed in the section Organization of Educational Environment. The general statistical data for the certification in 2024 of the mentioned categories of teachers are presented in table 1.

Table 1
Teacher certification statistics 2024.

Feature name	Quantitative value for teachers			
	Primary school	Ukrainian language	Mathematicians	Social sciences
Certified	1378	574	473	406
Exceeded threshold	776	473	187	332
% of exceeded threshold	56.3%	82.4%	39.5%	81.8%

5 tasks on digital competence for teachers of primary grades, Ukrainian language and mathematics were common and did not reflect the specifics of the use of digital technologies during teaching in a particular subject.

One of the most difficult for teachers of the specified subjects was the question to determine the address of a website that has an unsecured connection:

A) http://facebook; B) https://lib.nat.ua; C) https://apteka11.ua; D) it.bank.com.

The summary data of the teachers' responses are presented in table 2.

Table 2
The summary data of the teachers' responses.

	Key	Participants' responses (%)			
		A	B	C	D
Primary school	A	21.1	14.6	33.2	31.1
Ukrainian language	A	28.8	11.6	26.3	32.3
Mathematicians	A	32.3	13.3	25.7	28.1

Also, less than half of teachers of certain categories were able to determine the correct action in a situation when (table 3): *"For a month, while working with a PC, a window pops up with the message "Launching the software for this device is blocked because there are known problems when it works with Windows". Which of the following actions can help fix the problem?*

A) restart the computer

B) configure resources for the device

C) extend the software license validity period

D) update / install the necessary drivers

The next certification task concerned the purpose of the ¶ button in a word processor. About 90% of teachers completed it, possibly because the correct answer could be chosen by elimination. The

Table 3
The summary data of the teachers' responses.

	Key	Participants' responses (%)			
		A	B	C	D
primary school	A	21.1	14.6	33.2	31.1
Ukrainian language	A	28.8	11.6	26.3	32.3
mathematicians	A	32.3	13.3	25.7	28.1

test authors claimed that this task allows participants to demonstrate knowledge of the algorithm for performing basic operations with word processor objects [35, p. 49]. In our opinion, this claim is questionable – basic operations with word processor objects can be performed without using non-printing characters.

The task on the knowledge of online programs for organizing group work of students using virtual tools involved choosing one program that cannot be used for such a case: Miro, Linoit, Padlet, Kahoot. We believe that such tasks are not entirely correct, as they are oriented towards knowledge of specific software products. At the same time, the list includes programs that are actively used by teachers in classes. Successfully completed this task: primary school teachers – 31.5%, teachers of Ukrainian language and literature – 33.8%, mathematics teachers – 46.1%.

The last task from the digital competences block, in our opinion, allows for variability in the answers. To the question *"Which of the following actions can be implemented in the Google Docs environment?"* the proposed answers are:

A) create an electronic journal of student grades
B) automatically check the class's understanding of the topic
C) collect anonymous feedback on school attendance
D) conduct an automatic survey of parents about the child's behavior

If we mean by Google Docs a set of online programs that includes a word processor, spreadsheet, presentation editor, form editor, and graphic editor, then using them you can create various questionnaires, including anonymous ones. This can also be done using a spreadsheet. The formulation of task B is not entirely correct. Because the expression "class understanding of the topic" is not clear.

To determine the state of readiness for using digital technologies, a survey of teachers was conducted using an author's questionnaire containing questions related to: the frequency of using digital technologies in professional activities; digital tools used in work, programs and services for creating presentations; confidence in using digital technologies in the educational process; the level of digital competence; digital skills that need to be developed, etc.

The scope of the studied population was 136 teachers from Sumy, Poltava, and Chernihiv regions. The survey was conducted during in-service training courses in 2024.

The analysis of the responses showed that all teachers without exception regularly use digital technologies. Various online learning platforms are used by 93.3% of respondents, presentation programs by 100%, tools for creating educational videos by 52.2%, online conferencing platforms by 63.3%, and blogs and social networks for educational purposes by 54.4%.

The survey revealed that teachers need in-depth study of tools for creating interactive content – 58%, and the use of artificial intelligence in education – 35.3%.

47.8% of teachers assess their level of digital competence for effective work in modern conditions as sufficient, which is consistent with the results of previous testing on the Diia portal, indicating sufficient objectivity of the digital competence certification system for teachers.

4. Conclusions

The developers of test tasks for teacher certification are appropriately guided by the professional standard of a general secondary school teacher. The inclusion of a set of tasks for assessing digital competence in the certification is positive. However, given that the majority of teachers failed 4 out of 5 tasks in this block, we can speak of a low level of digital competence. However, the number of tasks, despite a fairly large sample (2831 people), is very small and does not cover even 10% of the content of the Conceptual and Reference Framework for Digital Competence of Pedagogical and Scientific-Pedagogical Workers [36].

We consider it necessary to ensure further progress of Ukraine on the path of European integration to introduce mandatory certification of pedagogical and scientific-pedagogical workers of educational institutions, taking into account the experience of teacher certification and materials of the Diia portal. Supplement certification tasks with competency tasks using computer technology, including computer networks.

In the future, it is proposed to conduct research to determine the structure of tasks for the comprehensive certification of pedagogical and scientific-pedagogical workers in digital competencies.

Declaration on Generative AI

The authors prepared this article without relying on artificial intelligence services.

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Digital management and digital leadership for the development of the digital educational environment of general secondary education institutions

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Abstract

The article is devoted to the issues of digital management in general secondary education institutions. The concept of digital leadership for the development of a digital educational environment as an important potential and tool for reforming the educational sector and modernizing the domestic digital educational space is considered. The vision of educators regarding current models and methods of developing leadership competence of teachers in the professional development system is presented. Its essence lies in the flexible combination of various components focused on the development of cognitive, operational-activity, and personal components of leadership competence. The main professional features of a modern digital leader are outlined, the main of which are strategic thinking, technological literacy, communication skills, security, adaptability, learning and development. The role of modern software and hardware complexes for the administration of general secondary education institutions, as well as digital tools for supporting management processes, communication, cooperation, creativity and innovation of the educational process at school is determined. The peculiarity of the study is taking into account international approaches to the development of professional qualities of teachers in the professional development system in the context of digital leadership in education, revealing the content of the characteristics of a digital leader and taking into account guidelines for improving professional skills. Conclusions and proposals for the implementation of digital leadership in education are presented, including strengthening the social component, communication, public relations, creating the school's image in social networks, involvement in professional networks, communication between teachers and experts and colleagues.

Keywords

pedagogical staff, digital leadership, education management, general secondary education institutions, professional development, digital environment of educational institution

1. Introduction

Digital management in education as an academic discipline is taught in many higher pedagogical educational institutions and institutions of postgraduate pedagogical education in Ukraine. The State Institution of Higher Education "University of Education Management" (hereinafter – the University) is a sectoral institution of higher education operating within the system of the National Academy of Educational Sciences of Ukraine. It conducts educational activities at the levels of higher education: first (bachelor's), second (master's), third (educational-scientific) and is a leading scientific and methodological center in the field of postgraduate education in Ukraine. Programs and courses of educational management are also taught in regional institutes/universities of postgraduate pedagogical education in Ukraine, domestic higher pedagogical educational institutions train specialists in the specialty "Management", implement courses "Management of an Educational Institution" and others.

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In modern conditions of digital transformation of education, managerial and leadership potential becomes one of the key conditions for the effective operation of an educational institution, and leadership becomes a tool for reforming the educational sector and modernizing the domestic digital educational space. In this context, leadership qualities are one of the main factors of self-organization and professional realization of pedagogical workers. Their identification and improvement is carried out through the development of leadership competence.

Issues related to the formation of leadership qualities today are inextricably linked with the use of technologies, the ability to manage processes and organize the learning environment. To create conditions for developing the leadership qualities of a modern teacher in the postgraduate education system, in addition to experience itself, an important role is played by what educational model will be applied and used during training. Thus, the main essence of such educational models lies in the combination of variable components, educational modules focused on the development of cognitive, operational-activity and personal components of leadership competence. The ratio of these components of leadership competence is determined according to the level of teacher leadership and prospects for its development at the stages of professional development in the inter-certification period. The issues of developing digital leadership and digital management have arisen today before Ukrainian education and before the entire educational community due to the fact that in recent years teachers have been directing their efforts to create a digital educational environment where students and all participants in the educational process can fully receive educational services. In recent years, schools have been forced to switch to distance learning mode. After the introduction of martial law in Ukraine, remote communication with students and parents has caused a number of challenges, where teachers and heads of institutions had to take responsibility for organizing and implementing distance learning. Digitalization has become both a trend in the world and an urgent necessity. The above-mentioned aspects have actualized the issue of developing leadership competence and digital leadership in modern conditions. The purpose of the article is to highlight the main components of digital leadership and digital management in education, especially in the context of strengthening the managerial component, communication, creating and maintaining the image of an educational institution and developing an educational digital environment.

Scientists consider digital leadership as a technological model of leadership that includes the effective use of technologies for the functioning of schools and achieving learning goals. Accordingly, to ensure these goals, attention is focused on the digitalization of the school environment and the transformation of the roles and responsibilities of school leaders and their effective performance of their digital roles [1, 2]. Munira Alajmi from Kuwait University, within the framework of her research, concluded that digital leadership in education fundamentally relies on modern digital tools and requires certain knowledge and skills from the leader for the effective use of these tools, which affects the improvement of student learning outcomes and affects the effectiveness of teachers' work [3]. Other scientists believe that digital leadership concerns not only competence and skills in one area, but also includes knowledge of other disciplines and arises as a result of combining management skills, administration and strategic thinking in addition to the ability to use digital tools for their activities [4, 5].

Issues of digital leadership in higher education institutions are also studied by Ghamrawi and Tamim [6]. Scientists consider the typology of digital leadership in higher education on the example of a large-scale mobile technology initiative. In particular, they emphasize the identification of the so-called 5D typology of digital leadership attributes, which includes digital competence, digital culture, digital differentiation, digital management and digital advocacy. Scientists discuss in detail how these attributes support the adaptive ability of a higher education institution to perceive digitalization [6]. Researchers also identify the main provisions of the theory and practice of digital leadership in education that are relevant to the international educational community [6]. Karakose et al. [7] examine teachers' perspectives on the digital leadership roles and technological capabilities of school principals during the COVID-19 pandemic. In particular, these scientists, based on the perception and experience of participants, identify such elements as the use of digital technologies, support for digital transformation, support for technology-based professional development, support for digital learning culture and digital leadership skills. Panshin et al. [8] provide a definition of the concept of a digital leader in education and investigate the impact of digitalization on the formation of leadership qualities.

Based on the results of practical and theoretical studies of the problem of digital leadership, the main provisions, characteristics and indicators of this phenomenon are highlighted [9, 10]. Research by Kopytko et al. [11] is devoted to the problem of digital leadership in education. The researchers carried out a theoretical analysis of approaches to the interpretation of digital leadership and proposed a model of digital leadership of an organization, including an educational institution, which can be developed and refined according to aspects of educational specifics.

The problem of digital leadership in higher education and the formation of leadership qualities of future teachers in the context of continuous development of digital technologies and digitalization of the educational environment in higher education institutions is considered by Sapohov et al. [12].

2. Research methodology

The following methods were used for the research: analysis of scientific and scientific-methodological literature, review of existing programs and approaches to the development of digital leadership; study and analysis of foreign sources for comparison with domestic experience and familiarization with approaches to defining the concepts of digital leader and leadership; analysis of classifications and characteristics regarding the management of an educational institution and digital, software and hardware support for this process.

The authors also took into account the comparative approach to research of phenomena in the educational, information-digital environment of general secondary education institutions.

3. Research results

Today, the educational process can take place regardless of time and place, which requires quick and easy access to information and educational resources. The digital learning environment is a tool that expands the ways and possibilities of providing and receiving educational services, ensures the implementation of educational process activities in mixed and online formats, provides equal access to quality education for all participants in the educational process.

The development and use of the digital environment of a general secondary education institution, where learning, growth, education, communication, exchange of experience, leisure activities of participants in the educational process take place, is associated with a number of advantages for participants in the educational process.

All participants in the educational process (teachers, school heads, students, parents and other stakeholders and institutions) who gain access to shared data and information, to such forms of learning as distance, remote work, group work, use a significant arsenal of digital learning tools, which contributes to increasing the effectiveness of education. At the same time, a key condition for the effectiveness of the educational process is the organization of management of an educational institution. Therefore, leadership in education is an important and integral component of the management process, which allows improving the learning and education process.

The phenomenon of leadership today has developed in the digital world and has emerged as a direction – *digital leadership*. The understanding of digital leadership is based on the general principles of leadership theories, among which the main ones are situational, functional, behavioral, and integral theories. The problem of leadership in education is considered by foreign and domestic scientists and practitioners of education as a complex concept, namely: as a phenomenon, a form of educational practice, as a socio-psychological process, as a personality characteristic, etc.

Modern education, like all other public sectors, needs a completely new type of leader – a *digital leader*. After all, a teacher must navigate modern trends in the application of digital technologies and be an active participant in creating the digital environment of an educational institution, having a high level of digital competence and the need for its further development, create teams, maintain connections between participants in the educational process, cooperate and establish connections with stakeholders, actively involve them and work together to achieve a common goal, overcome communication barriers, competently communicate when performing professional tasks, be able to self-present, as well as develop a culture of innovation, ethics, competitiveness, risk resistance and constantly self-improve and develop.

As noted by Panshin et al. [8], digital leaders differ from non-leaders in various skills, attitudes, knowledge, as well as professional and personal experience. Digital leaders must be flexible, able to adapt and strive for intellectual curiosity and new knowledge. They should be open to continuous learning, seeking solutions globally, and should constantly encourage their employees and followers to learn [8].

Taking into account the above definitions of digital leadership and digital leader, it is worth exploring certain characteristics of such leaders, as presented in the works of researchers, and determining how it is necessary to support this direction in education. It is also important to realize the role of technologies and the level of digitalization of educational institutions that contribute to creating conditions for digital leadership.

To understand how teachers demonstrate their leadership, it is necessary to use tools for monitoring their leadership competencies, particularly when they take professional development courses. Monitoring the quality of educational services during professional development is a complex task today, as there are no reference indicators of the quality of such services, including for determining provisions related to the digital leadership of the head of an educational institution, teacher and pedagogical worker. Despite existing professional standards, it is very difficult to assess leadership. That is why, to stimulate the development of leadership qualities of professionals in education, it is worth creating models of professional development in accordance with the requests of individuals and educational institutions. Sapohov et al. [12] identified the main professional competencies and skills of a modern digital leader, the main components of which are strategic thinking, technological literacy, communication skills, security, adaptability, learning and development.

For example, the team of the Bila Tserkva Institute of Continuing Education developed and implemented the software complex “School of Leaders of Professional Education as an Innovative Model of Teacher Training in Conditions of Sustainable Development”. The software complex is based on a new model of training educational leaders and managers according to their requests [13]. Scientists provided a vision, a model for the director of professional training, which the team started. Key elements are supporting the competent development of education workers at all stages of their education and professional trajectory. This model includes the development of profiles of the main skills of teachers that are developed in advanced training systems: integrated abilities, general abilities (education, regulation), special abilities (andragogical, scientific-methodological, research, civic, competence in informal education and professional-personal development; psychological-facilitative; entrepreneurial digital, etc.). Thus, a modern leader is characterized as a person who: thinks globally, foresees potential, formulates a general vision of the future; approves changes, demonstrates awareness of the latest technologies, encourages constructive criticism, achieves success in competition; promotes the development of people’s abilities, delegates authority, values sincerity in people; shows readiness for joint management, develops teamwork, a sense of partnership, cares about people’s satisfaction; demonstrates personal achievements, a high level of competence, acts flexibly, in accordance with the requirements of the situation and proclaimed values and mission.

The head of an educational institution, as a leader, must have the following skills and abilities: ability to manage oneself and one’s time; civic and socially important personal values; strategic vision; personal responsibility; striving for constant self-improvement; problem-solving skills; creativity and ability to innovate; knowledge of modern methods of influence; ability to influence others, convince them; ability to teach and develop subordinates; ability to form and develop effective teams.

To solve tasks and ensure the educational process, the head of an educational institution, in particular a general secondary education institution, uses electronic software and hardware complexes, which include, for example, the Software and Hardware Complex “Automated Information Complex of Educational Management” (PAC “AIKOM”). This is an EMIS class system (Education Management Information System, electronic education management system), designed for processing state electronic information resources and personal data in the field of education within a single integrated environment. The main task of such a complex is to ensure the transition to electronic document flow (reporting, communication, notifications, surveys, voting, operational data collection) and optimization of business processes in the field of preschool, general secondary, extracurricular and professional (vocational-technical) education, as well as education management at local and regional levels (creation of appropriate modules in PAC “AIKOM”) [14]. Such a complex allows to significantly improve the reliability of educational statistical and management information and improve on this basis the quality of management decisions, in particular regarding the distribution of educational subvention funds and other budget money for education, creates prerequisites for abandoning paper documents within the framework of general debureaucratization, etc. At the same time, the administration of the institution has the opportunity to quickly prepare educational reports, charts of success by classes and subjects; analyze the effectiveness of teachers’ work; keep records of attendance; track the dynamics of success of students, classes, schools; increase the rating of the educational institution.

For teachers, the use of software and hardware complexes helps to get rid of unnecessary paperwork; provides easy access to the current schedule on a smartphone or computer; allows downloading educational materials for study and assistance in preparing homework; saves time on lesson preparation; allows convenient division of classes into groups without paper journals; performs simple automatic formation of complex reports based on the results of the semester or academic year; establishes effective communication with students and parents.

For students, AIKOM as a service provides: convenient access to educational materials and homework; participation in online webinars and conferences organized by the school; viewing lesson materials at a convenient time (in particular, during absence from school) and the possibility of remote interaction with teachers; conditions for independent control of learning success. At the same time, parents can quickly learn about children’s success and attendance; effectively control acquired knowledge and homework completion; interact and communicate with teachers, as well as participate in assessing the quality of educational services, including digital ones.

There are a number of digital tools that are effective for supporting management processes, communication, cooperation, creativity and innovation, including Lean Canvas, StudDiary, Google Classroom, distance learning systems - Moodle, ATutor, Claroline, Dokeos, LAMS, OLAT and others.

Ghamrawi and Tamim [6] consider the characteristics of digital leadership in higher education institutions to be a combination of five components, namely:

- digital competence,
- digital culture,
- digital differentiation,
- digital management,
- digital advocacy.

The “5D Typology for Digital Leadership” approach [6], the elements of which were identified during a survey within the framework of the conducted research, will be effective for implementation in the university management system and will contribute to its development in the context of modern processes of digital transformation [6].

Regarding school education, according to Zhong [15], strategies for digital leadership in secondary education institutions should be:

- Visionary Leadership,
- Digital Age Learning Culture,
- Professional Development,
- Systemic Improvement,
- Digital Citizenship.

Kopytko et al. [11] proposed a model of digital leadership of an organization, in particular an educational institution, which can be developed and refined in aspects of educational specifics (figure 1).

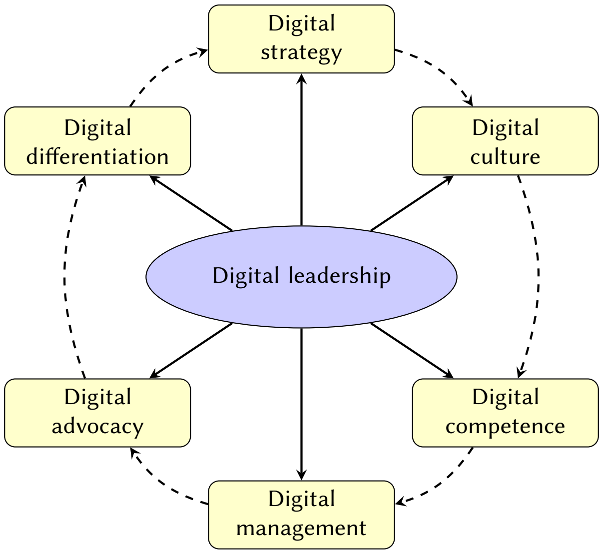

Figure 1: Model of digital leadership (based on Kopytko et al. [11]).

Researcher and practitioner, former principal of New Milford High School, USA, Eric Sheninger, who is a specialist in digital technologies in education and an expert on digital leadership in education, believes that digital leadership begins with identifying obstacles to making changes and making specific decisions to overcome them in order to prepare the school for the challenges of the digital age [16]. The scientist identified seven directions of digital leadership – seven pillars of digital leadership in education, the content of which contains certain guidelines for digital leaders and the development of digital leadership, which we will consider in more detail:

1. *Communication.* Digital leadership is about engaging all stakeholders in communication. Important information can be transmitted using various digital tools, including free ones, social networks and simple implementation strategies to satisfy stakeholders in the digital age.
2. *Public relations.* Forming the foundation of a public relations platform, using free social media tools with the ability to control content. Digital leaders should become the main narrators of educational policy and events of the educational institution, form a positive image of the educational institution based on best practices and achievements, create the necessary level of transparency in an era of negative rhetoric regarding education.
3. *Branding.* The branding of any organization plays an important role in its impact on current and potential consumers. Digital leaders can use digital technologies to create a positive brand presence that emphasizes positive aspects of school culture, demonstrates the reputation of the educational institution, increases community pride and helps attract parents and the public.
4. *Student engagement.* School education should reflect real life. Digital leaders must understand that students should use the digital tools they use outside of school, create learning artifacts that demonstrate conceptual mastery. This is an important pedagogical shift as it focuses on improving core skill sets, namely: communication, collaboration, creativity, media literacy, global connectivity, critical thinking and problem solving that society requires. With a sound pedagogical foundation, digital tools and social networks provide students with the opportunity to take more responsibility for their learning.
5. *Professional growth and development.* Being at the forefront of digital technologies in education, keeping up with the times and implementing the achievements of science and technology in the educational process is possible thanks to professional growth and development. Using the capabilities of social networks provides the opportunity for support and feedback. Leaders can form their own personal learning network (PLN) for their own learning needs, resources, connections with experts in the field of education, with practitioners, as well as for discussing issues to improve teaching, learning and leadership.

6. *Reimagining the learning environment.* This direction of implementing digital leadership should be implemented after digital leaders understand the foundations laid in previous directions, understand how to use them to initiate sustainable changes. The next step is to begin the digital transformation of the learning space and environment. Digital leaders must begin to create or develop a vision and strategic plan dedicated to learning in the digital world. To do this, digital leaders must know the characteristics and dynamics of development and innovation of digital learning environments, such as Bring Your Own Device (BYOD), blended learning, flipped classroom, gamification, virtual learning and others.
7. *Opportunities.* It is important for digital leaders to consistently look for ways to improve existing programs, resources and professional development. Digital leaders use connections, increase opportunities for improvement in various areas of school culture. They must be catalysts for change and must transform their schools into ones that prepare students to master the necessary skills of the digital age while engaging various stakeholders.

The approach to implementing digital leadership in education proposed by Sheninger [16] can be called socially-oriented, focused on the social component, in particular, communication, public relations, creating the school's image in social networks, involvement in professional networks, communication with experts and colleagues.

4. Conclusions and prospects for further research

Thus, the general strategies for implementing digital leadership are understanding digital transformation and its impacts, involving all participants in the educational process in digitalization processes, communication and public relations, creating a policy of a general secondary education institution regarding the use of digital technologies, developing the digital educational environment of an educational institution and its infrastructure, professional improvement and development, digital management. It is also worth paying attention to digital advocacy and digital citizenship – aspects non-traditional for school education. When considering the problem of digital leadership, it is necessary to separately focus on such an important aspect as digital ethics. Undoubtedly, digital leadership in education must be ethical, follow social norms of behavior in the digital world and professional ethics of the educational sector in the context of digitalization, based on the principles of integrity, respect, benevolence, compliance with subordination, respect for personal boundaries, psychological comfort, resource savings, traditionalism and principles of confidentiality and security. Consideration of the problems of digital leadership in education and the digital leader is an object for further research.

We believe that it is important to expand prospects for teachers in improving professional skills, in particular – determining specific topics for possible professional development courses: academic integrity, protection of personal data, virtual laboratories, stress resistance and others. Now, in wartime conditions, it is important to conduct current analysis and regular monitoring of the current state of technical and scientific-methodological equipment of schools, to focus attention personally on teachers regarding their ability to implement distance learning with students. Attention should be paid to those teachers and pedagogical workers who conduct distance learning for internally displaced children and refugee children, as well as to those teachers who implement distance learning for children from occupied territories.

Among future research directions, it is also important to focus on the impact of the digital educational space on the success of schoolchildren; creating tools and methods for supporting online learning in various academic disciplines; identifying problems and developing innovative, effective scientifically based online tools and providing scientific and methodological support; developing new digital platforms and educational environments with accessible and free online materials for teachers of all subjects.

Declaration on Generative AI

The authors have not employed any generative AI tools.

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Mobile learning under martial law: the role of mobile applications in students' educational activities

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Abstract

This article examines the current state and key features of mobile learning among secondary school students in Ukraine under martial law. The aim of the study is to determine how mobile applications and smartphones are used for educational purposes, identify age-related patterns of use, and assess students' attitudes towards mobile learning. The research is based on a quantitative survey conducted in February 2025 with 962 students aged 10 to 18 from various regions of Ukraine. The results show that students actively use applications such as Google Classroom, Zoom, Duolingo, and ChatGPT for both formal and informal learning. For self-education, especially among high school students, apps are used to prepare for the national multi-subject test, while TikTok and YouTube are used for leisure. It was found that students prefer gamified and interactive applications. The results confirm the role of mobile learning as a flexible and accessible educational tool in times of crisis. At the same time, issues such as digital inequality, limited live interaction, and health risks are highlighted. The article contributes to the understanding of mobile learning as a distinct educational phenomenon and offers practical recommendations for its effective integration into the Ukrainian school system.

Keywords

general secondary education institution, mobile learning, ICT in education, mobile applications

1. Introduction

In the 21st century, mobile learning has become one of the key forms of transforming the educational environment, especially in times of crisis. Military conflicts, such as the full-scale invasion of Ukraine by the Russian Federation in 2022, have changed the forms and means of access to education, presenting certain challenges for students and teachers [1, 2]. In this context, mobile devices and applications appear not only as additional learning tools but as a critically important platform for ensuring a continuous educational process.

Under martial law, mobile learning has become the only means of receiving education for a significant part of the population that has been displaced or found itself in combat zones. Ukraine, as a country with a relatively high level of digitalization in education before the war, was able to mobilize digital resources at the national level, such as the "All-Ukrainian Online School" and the "Diia.Osvita" platform. Educational institutions intensified the educational process using Google Classroom, Microsoft Teams, Zoom, Google Meet, which made it possible to minimize learning losses. The role of mobile applications in this process is difficult to overestimate. They not only enable synchronous and asynchronous learning but also provide psychological support, motivation, and student autonomy.

Research on mobile learning conducted during martial law in Ukraine, particularly the work of Sipii et al. [3], proves that mobile education is a tool for increasing accessibility and equity in learning. Researchers confirm the important role of mobile learning in implementing the principle of equal access to education, especially during wartime.

Similar research results are reflected in the work of Onopriienko [4], which proves that mobile learning for students of general secondary education institutions during military operations contributes to the continuity of the learning process and helps avoid learning losses. Gamification of learning and

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visualization of educational material are advantages of mobile learning as opposed to purely distance learning [5, 6, 7].

In the work of Naveed et al. [8] a literature review on the organization of mobile learning showed that in formal education organized by an educational institution, mobile learning may not have all the advantages over traditional methods. However, under conditions of limited access to education, mobile learning promotes interactivity and makes the learning process personalized.

According to the reviewed studies on mobile learning organization, it can be noted that mobile technologies contribute to increasing students' motivation, developing critical thinking, and self-organization skills, which is especially important in conditions of instability. Moreover, due to their accessibility, mobile applications promote inclusion: they allow children from rural areas, internally displaced persons, and children with special educational needs to learn.

At the same time, the use of mobile technologies during wartime has its risks and limitations. Among them are the low level of digital literacy in certain population groups, as well as psychological stress associated with living under constant pressure. However, these challenges do not diminish the importance of mobile learning, but rather emphasize the need for the development of specialized strategies adapted to wartime conditions.

Thus, mobile applications serve not only as a technological but also as a socio-pedagogical phenomenon that ensures educational resilience. In wartime conditions, they become the main bridge between students and knowledge, between today's challenges and tomorrow's opportunities. This requires in-depth scientific analysis and the development of practical recommendations for educational policy, technological solutions, and pedagogical support.

2. Related work

The analysis of recent studies and publications has shown that mobile learning remains an effective form of organizing the learning process despite its relatively short history [9]. Mobile learning is often considered to originate from e-learning, which integrates mobile devices and technologies into the educational process [10]. Although the first experiments with the use of mobile devices in education began appearing in the early 2000s, the active implementation of mobile learning elements in educational institutions started around 2009 [11] and was initially reflected only in publications related to higher education institutions. Research and practice have demonstrated the effectiveness of mobile technologies in supporting and expanding traditional learning opportunities, particularly in providing access to educational materials, facilitating communication between students and teachers, completing assignments, and assessing learning outcomes.

A comprehensive analysis of the problem of organizing mobile learning in educational institutions, conducted by Crompton and Burke [12] covering the period from 2005 to 2016, revealed a significant positive impact on students' learning outcomes. Mobile learning proved especially effective in the field of foreign language acquisition. Since 2011, studies on mobile learning have confirmed the effectiveness of mobile devices not only for education but also for social interaction, work, and entertainment [13].

Between 2016 and 2018, the use of mobile learning in educational institutions allowed for the identification of its key advantages [14]: 1) the ability to access educational information, receive answers to questions, read e-books, and listen to podcasts; 2) access to learning tools, including educational programs, videos, educational games, and electronic libraries; 3) the transition from synchronous to asynchronous learning; 4) participation in virtual learning communities.

During this period, mobile learning also gained new significance as Apple and Google introduced their own augmented reality development kits for iOS and Android platforms, respectively. This became a significant push toward the organization of immersive mobile learning in educational institutions.

A report published by UNESCO in 2023 [15], identified mobile learning as one of the key factors in ensuring access to quality education in secondary schools, particularly in countries with medium and low incomes. Analysis conducted as part of mobile learning support initiatives in these countries indicates that mobile devices serve not only as tools for accessing educational materials but also as platforms for communication, exchange of ideas, and discussion of complex issues with teachers and peers.

In Ukraine, the issue of using mobile phones in the learning process was first raised in early 2000s by Semerikov [16] who developed and successfully implemented a methodological system for teaching informatics disciplines, integrating elements of mobile learning. The research results confirmed the effectiveness of this approach for both university students and high school students in general secondary education institutions. However, despite its significant potential, mobile learning at the time did not become widely adopted as the sole form of education in Ukraine. Instead, it acted as a catalyst for changes in traditional learning, contributing to the emergence of a new, more flexible model – blended learning, which became widely used in secondary schools starting in April 2020 [17, 18].

Another important issue that can be addressed through the implementation of mobile learning is the organization of education for students who have become refugees from war-affected countries. Since 2013, the large number of forcibly displaced minor students from Syria, Afghanistan, and East Africa has led to discussions in the global community about the risks of a "lost generation" due to the inability to obtain quality secondary education [19]. A similar issue of educational losses has affected Ukrainian students following Russia's full-scale invasion in February 2022, as evidenced by the PISA study [20]. Solving this problem requires a comprehensive approach, with one of the key elements being the use of mobile information and communication technologies to create a flexible and effective learning environment.

Despite programs implemented by the United Nations to address educational losses in war-affected countries through mobile technologies, the effectiveness of these efforts has not yet been sufficiently confirmed. Therefore, the key challenge for Ukrainian students in acquiring knowledge consciously is to create a personalized learning environment enriched with mobile information and communication technologies.

3. Problem statement

Despite the fact that mobile learning is a multifaceted educational process, an analysis of scientific publications has revealed several issues related to the use of mobile devices in general education institutions. Despite more than a decade of mobile learning development, it is impossible to unequivocally state that there are enough effective pedagogical strategies to integrate mobile devices into the educational process in a way that enhances its effectiveness. One of the key challenges is creating a balanced approach to using mobile devices both within and outside educational institutions. This approach should consider both psychological and pedagogical aspects of mobile technology use, as well as the development of appropriate methodologies and the selection of suitable tools.

Under martial law, when traditional forms of education face significant restrictions, mobile learning becomes a critically important tool for ensuring the continuity of the educational process in Ukraine. Mobile devices, particularly smartphones, play a crucial role as tools that allow students to access educational materials, communicate with teachers and classmates, and maintain a connection with their classroom, school, or specific subject teachers. The organization of psychological support for students studying under martial law conditions also cannot be overlooked. Mobile devices can serve as tools for providing psychological assistance and support.

The features of mobile learning listed above prove that under martial law in general secondary education institutions, ensuring the quality of mobile learning is an important issue. To develop effective pedagogical strategies and methodologies that contribute to achieving educational goals, it is necessary to conduct a thorough analysis of mobile device and application usage among students in Ukrainian general education institutions, as well as their individual approaches to organizing learning through mobile devices. This is crucial for achieving personalized learning and student autonomy.

Based on the obtained results, the issue of developing effective strategies and methodologies for using mobile devices in the educational process arises. Addressing these challenges is essential for ensuring the continuity and quality of education in Ukraine, as well as for supporting students' psychological well-being.

4. Methods of research

This study used a quantitative research analysis through an anonymous structured online survey to collect data on students' use of mobile devices and educational applications. The survey was conducted in February 2025 and involved 962 students in grades 5–11, aged 10 to 17, from general secondary education institutions across various regions of Ukraine (Kyiv, Odesa, Dnipro, Khmelnytskyi, Kryvyi Rih, Lysychansk). The authors' approach ensured regional representation and diversity in access to digital technologies. The tool used was a closed questionnaire developed by the authors and validated by experts in educational technology. It included single-choice questions and a Likert scale aimed at identifying: the types of mobile devices and operating systems used; the most frequently used educational and entertainment apps; the frequency and purpose of mobile app use; students' attitudes towards mobile learning and gamified educational tools; and self-assessments of academic and creative benefits of mobile learning. Descriptive statistics and focus group results were used to analyze the responses. The data were processed to identify age-related trends, usage patterns, and educational needs across different groups. The study adhered to ethical standards, ensuring the anonymity of participants and their voluntary consent.

The results of the study made it possible to identify trends in the use of mobile devices and applications by students under martial law, as well as to determine challenges and opportunities for implementing mobile learning in general secondary education institutions in Ukraine.

5. Research results

5.1. Theoretical foundations of mobile learning

Despite the widespread adoption of mobile learning in the educational community, scientific literature presents an ambiguous perception of the term "mobile learning". The understanding of this concept ranges from the simple use of a mobile device for communication with a teacher or sending and receiving educational materials (e.g., via messaging apps) to a more profound interpretation – as a tool that creates conditions for the high-quality organization of a full-fledged learning process. The latter involves using mobile applications for education, creating interactive assignments, developing mobile learning courses and platforms, which allow for personalized learning and engaging students in educational activities.

The COVID-19 pandemic, in turn, not only facilitated the mass transition of educational institutions to mobile learning but also served as a powerful impetus for the development and refinement of various educational applications that are successfully used in educational processes worldwide.

Given the above, mobile learning can be considered one of the innovative forms of organizing the learning process, provided that:

- it is conducted using mobile devices with free access to educational materials, resources, and applications that facilitate the process of understanding and visualizing educational content;
- it allows free communication with other participants in the learning process;
- it provides unlimited access to Internet resources;
- it can take place anywhere and at any time. The organization of mobile learning enables the use of ready-made or the creation of unique educational materials delivered through mobile applications that promote collaborative project-based activities.

Among the advantages of mobile learning in general secondary education institutions, the following can be highlighted.

First. The flexibility and accessibility of the learning process gain particular importance in wartime conditions. Mobile technologies enable students to independently choose the time they can devote to learning, which is critically important when the regular learning schedule is disrupted. For students of

Ukrainian educational institutions, who are often forced to relocate, stay in shelters, or live abroad, the flexibility of the learning process helps maintain their motivation for education, as the pace and intensity of their learning depend on their physical and emotional state, access to a safe place, and the ability to connect to the Internet.

Another important factor in the accessibility of mobile learning is the ability for students to access various educational resources and platforms. Ukrainian students have the opportunity to study using platforms such as:

- "All-Ukrainian Online School" (https://lms.e-school.net.ua/) – an official free platform for distance and blended learning, developed by the Ministry of Education and Science of Ukraine during the 2020 pandemic. The purpose of creating this platform was to ensure equal access to quality education for all students from grades 5 to 11;
- ARBook (https://arbook.info/) – an innovative educational platform that combines traditional learning materials with augmented reality (AR) and virtual reality (VR) technologies [21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32]. This educational platform was launched as an educational project in July 2022 with the support of the Ministry of Education and Science of Ukraine to ensure an uninterrupted learning process in wartime conditions. Its task is to create interactive learning materials that make education more engaging and effective for students of different ages;
- MozaBook (https://ua.mozaweb.com/uk) – a comprehensive educational platform developed by Mozaik Education, offering interactive tools and materials for learning. This platform combines traditional teaching methods with modern digital technologies, enabling the organization of the learning process.

Using a mobile device for organizing the learning process allows students to download various educational applications and learning materials, which they can review at their own pace and revisit difficult topics; educational gaming applications that not only facilitate students' knowledge acquisition but also motivate them to learn.

Speaking about the accessibility of mobile learning, attention should also be focused on the possibility of organizing inclusive education adapted for children with special educational needs.

Second. Personalization of the learning process. Mobile technologies allow students to shape their own educational trajectory by adapting the learning process to their individual needs. Through access to mobile platforms, students independently determine the complexity of the material based on their level of knowledge and self-learning skills and choose the most optimal learning format for themselves (text, video, illustrations, diagrams), taking into account their psychological characteristics.

The personalization of the learning process is a powerful motivational factor for students. If the learning process aligns with students' interests and needs, they become more engaged in education and, consequently, more motivated. Receiving instant feedback while completing tasks also helps enhance learning motivation and effectiveness.

A particularly significant role in learning personalization is played by generative artificial intelligence (AI), which can serve as a personal assistant for students [33, 34, 35]. AI algorithms analyze the user's progress, identify weaknesses in knowledge, and offer individually tailored tasks and materials to overcome difficulties [36].

Third. Interactivity is a key element of modern education, and mobile technologies create limitless opportunities for this. Mobile applications and platforms enable teachers to create or use ready-made interactive learning materials, such as video lessons with interactive elements, virtual laboratory work, online games, and quizzes. This contributes to a more engaging and exciting learning experience, as modern students, regardless of age, can be interested in the learning process through a system of accumulated points and rewards organized as a game.

At this stage of the education system's development, interactivity and assessment can also be organized through the use of immersive technologies in the learning process. The use of such technologies allows students to take virtual tours, model events, conduct experiments, and visualize abstract concepts – all of which contribute to better assimilation of learning material and increased student motivation and can be done without teacher intervention [37, 38, 39, 40].

Fourth. The organization of microlearning is a modern and effective approach to organizing education, in which educational information is presented in small, logically complete didactic units. This division of material not only facilitates its processing and assimilation in a mobile format but also helps improve concentration, as students can focus on a small portion of educational material at a time. Microlearning also allows students to independently choose the pace of learning, revisit difficult topics, and repeat material at a convenient time. This format is especially beneficial for students with low concentration levels, as short and clear educational blocks help them maintain focus and avoid overload. Additionally, microlearning can be more interesting and engaging due to the use of various formats for presenting educational information: videos, infographics, interactive tasks, and tests.

All the listed advantages of mobile learning are interrelated components that make it possible to define the key principles of mobile learning in general secondary education institutions: flexibility and adaptability; accessibility and diversity; personalization and motivation; interactivity and immersive ness; autonomy and independence; safety and support.

5.2. The appropriateness of using mobile devices under martial law

As of the end of 2024, according to UNESCO, 79 education systems worldwide (around 40%) had implemented bans on smartphone use in schools. These measures aim to reduce distractions, improve student concentration, and address issues related to mental health and cyberbullying [41].

Here are some countries that have implemented such bans:

- *China.* Since 2021, students have been prohibited from bringing mobile phones to school without written parental permission. The goal is to protect eyesight, improve concentration, and prevent internet addiction [42].
- *Brazil.* In 2024, a federal law was adopted that prohibits smartphone use in schools, except in emergencies, for educational purposes, or for students with disabilities [43].
- *Denmark.* In 2025, the government announced a ban on mobile phones in schools and after-school programs for children aged 7 to 16–17, based on the recommendations of a child welfare commission [44].

These measures reflect a global trend toward limiting the use of mobile devices in educational institutions and raise the issue of developing a culture of using these devices for learning purposes.

Under martial law, mobile phones can serve as an important tool for ensuring learning continuity, maintaining communication between students, teachers, and parents, and providing access to educational materials and information. They can become a platform for interactive learning, knowledge exchange, and psychological support for students and teachers.

When comparing three forms of learning – distance, blended, and mobile learning – that can be implemented under martial law, we can conclude that mobile learning is the most flexible, adaptive, and viable one (table 1).

Unlike traditional models of distance learning, mobile learning relies not only on Wi-Fi availability but also on the ability to use mobile networks (3G, 4G, 5G). This significantly expands access to educational content even in emergency situations, particularly under martial law, when wired internet may be unavailable. In many cases, mobile connectivity remains the only stable communication channel, making mobile learning a realistic and viable alternative to traditional forms of educational activity.

While distance learning is entirely dependent on stable internet connections and specialized equipment, and blended learning requires periodic physical presence in educational institutions – which can be dangerous or impossible under certain conditions – mobile learning offers a more flexible and adaptive model. It leverages the advantages of learners' existing personal devices and enables learning to take place anytime and anywhere. Even under limited or unstable connectivity, learners can access study materials, communicate with teachers and peers, and complete assignments with a high degree of autonomy. These very characteristics make mobile learning particularly relevant in crisis situations and for ensuring the continuity of the educational process.

Table 1
Comparative table of three learning formats: distance, blended, and mobile learning.

Criterion	Distance learning	Blended learning	Mobile learning
Place of learning	Online (remotely)	Combination of online and in-person learning	Anywhere (via mobile devices)
Time of learning	Fixed schedule or asynchronous	Mixed: partly scheduled, partly flexible	Mostly asynchronous, at a convenient time
Learning device	PC, laptop	PC, laptop, sometimes tablet	Smartphone, tablet
Use of mobile devices	Partially (apps, messaging)	Interactive elements during sessions	Main learning tool
Content formats	Video lectures, tests, forums	Face-to-face and online activities, group work	Micro-content, podcasts, interactive applications
Role of the instructor	Facilitator, coordinator	Mentor, organizer of content and activities	Mentor offering micro-learning
Accessibility	Requires a stable internet connection	Depends on the stage (online/offline)	High (if smartphone and internet access are available)
Student motivation	Depends on self-discipline	Supported through interaction	Increases through flexibility and gamification

The concept of mobile learning is broader than that of blended learning, as it encompasses the process of acquiring knowledge through mobile devices in a user-friendly mode. It can be organized within the framework of formal education as well as self-directed learning, providing high mobility and flexibility in the learning process. In contrast, blended learning combines traditional in-person formats with elements of online education, aiming to merge the advantages of both approaches.

The key differences between these forms lie in the tools and formats used to organize learning. Mobile learning is predominantly conducted via smartphones or tablets, whereas blended learning uses both digital (computers, interactive platforms) and traditional (printed materials, chalkboards) tools. Mobile learning emphasizes mostly asynchronous online interaction, granting learners greater freedom and personalization. Blended learning, on the other hand, integrates digital communication with face-to-face interaction and is usually based on a synchronous schedule.

Thus, mobile learning emerges as a means of individualized, flexible, and accessible education – especially relevant during crises – while blended learning remains an effective model for structured integration of diverse educational formats.

5.3. Challenges of using mobile learning in the educational process

Mobile learning, as an important part of the modern educational process, provides students and teachers with new opportunities for learning and development. However, along with undeniable advantages, it also presents challenges that require careful analysis and a balanced approach to their resolution within the general secondary education system of Ukraine:

- *limited access to Internet resources remains a problem for some students in Ukraine* – this applies to students from rural areas, where mobile Internet coverage may be insufficient or of poor quality, as well as to students in cities experiencing damaged infrastructure and power outages. The cost of mobile Internet should also not be overlooked, as it may be too high for some families. While the issue of providing students with mobile devices has been partially resolved through government programs, other important aspects still require attention and funding. These include the development of high-quality educational materials adapted for mobile devices, accessibility of educational mobile applications, teacher training on the use of mobile technologies in education, and the provision of technical support for students and teachers;
- *lack of live communication* – live communication is an important factor for speech development, communication skills, and the social adaptation of children. A lack of face-to-face interaction may lead to difficulties in constructing complex sentences, inaccurate word usage, problems

understanding abstract concepts, and other aspects of speech development. This drawback of mobile learning can be easily addressed by organizing communication and interaction between students even during video conferences, online forums, and collaborative projects. It is important for teachers to effectively use these tools to develop students' speech and communication competence. Another important factor in this issue is the psychological support of students, which is easier and more effective in face-to-face communication. Personal communication between a teacher or psychologist and a student allows for a quicker response to changes in their behavior;

- *insufficient development of independent learning skills among students, especially younger and middle school students* – a low level of self-organization and self-control can make learning through mobile devices more difficult. Constant air raid alerts provoke a stressful state in students, which in turn reduces their concentration and self-discipline;
- *deterioration of health* – prolonged use of mobile devices can lead to eye strain and nervous system fatigue, make students more irritable, and reduce their physical activity. However, these risks can be minimized by organizing the educational process according to the blended learning model – a combination of traditional education with mobile information and communication technologies.

Despite the mentioned challenges, mobile learning remains a relevant form of organizing the educational process under martial law.

5.4. The state of mobile application usage among 5th-11th grade students under martial law

Modern digital technologies play a key role in transforming the educational process. In particular, mobile devices have become an integral part of learning, providing access to educational resources, interactive tasks, and communication platforms. The use of smartphones among students generates both positive expectations related to expanded opportunities for independent learning and concerns regarding their role in distracting from the educational process.

The development of mobile technologies creates unique opportunities for personalized learning [45], gamification of educational processes [46, 47], and enhanced communication efficiency among participants in the educational environment. However, despite the wide range of digital services that can contribute to improved learning, their usage level among students remains uneven. Research on the use of mobile services in the educational process is relevant, as it provides insight into which digital tools are most frequently used by students, for what purposes, and what challenges educators face in this context.

In February 2025, researchers from the Institute of Educational Digitalization of the National Academy of Educational Sciences of Ukraine conducted a survey of 962 students in grades 5-11 regarding their use of mobile phones for learning, self-education, and entertainment. The survey provided a variety of perspectives and experiences, covering students from different regions of Ukraine, namely: Dnipro, Dnipropetrovsk region – 19.23%, Kyiv – 37.17%, Odesa, Odesa region – 16.53%, Khmelnytskyi, Khmelnytskyi region – 9.46%, Kryvyi Rih, Dnipropetrovsk region – 14.97%, Lysychansk, Luhansk region – 2.6%.

Students aged 10 to 18 participated in the study, allowing for an analysis of mobile phone usage across different age groups. The most active participants were students aged 14-15, which may be associated with a period of active social life and education (figure 1).

The mobile phones used by students run the following operating systems: Android – 58%, iOS – 39%, Windows Phone – 3%.

Among the most popular educational applications, students mentioned Google Classroom, Zoom, Teams, Quizlet, Duolingo, and Photomath. Most students use these apps for completing homework, preparing for tests, and learning foreign languages. Some students also use applications for reading books, scanning documents, and taking notes (figure 2).

The selection of these applications is based on the fact that students installed them on their mobile phones for specific purposes, including:

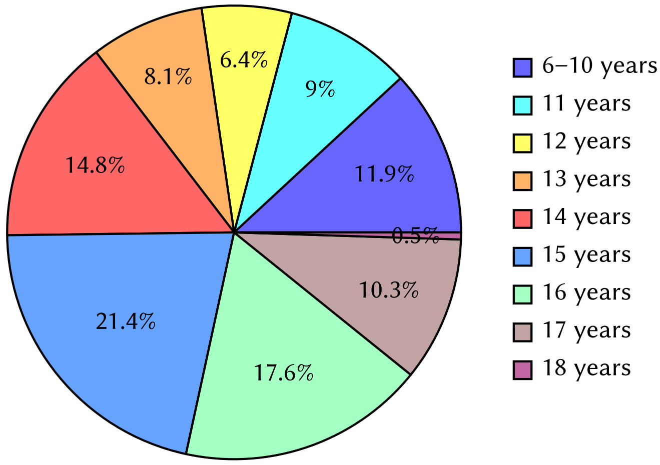

Figure 1: Distribution of students by age group.

- Google Classroom – for organizing learning, completing assignments, and communicating with teachers;
- Zoom / Google Meet – for online lessons, video conferences, and group discussions;
- Yedyna Shkola / Moia Shkola – access to learning materials, schedules, grades, homework, and teacher communication;
- Teams – for project collaboration, messaging, and video conferencing;
- Novi Znannia – a digital diary with distance learning features;
- Photomath – for solving math problems and explaining solutions;
- Duolingo – for learning foreign languages in a gamified format;
- ChatGPT – for getting answers to questions, assistance with learning, and completing tasks;
- Quizlet – for creating and using flashcards, quizzes for memorizing educational information, key concepts, and formulas;
- Viber – for communicating with classmates, messaging, and calls;
- Canva – for creating presentations, infographics, and project designs;
- Proste ZNO – for preparing for external independent testing (ZNO);
- Outlook – an email service for communication with teachers and classmates.

These applications help students organize their studies, gain new knowledge, and communicate effectively.

Analyzing mobile applications across different age groups, we found that: ages 10-11 – younger students who are just beginning to use digital tools in learning, with the most common apps being Google Classroom, Zoom, Duolingo, and Yedyna Shkola; ages 12-14 – middle school students who actively use various applications for learning and communication, including Teams, Canva, Photomath, and Quizlet; ages 15-17 – high school students preparing for exams and university entrance, favoring more specialized educational apps such as Google Meet, ChatGPT, Novi Znannia, and Proste ZNO.

We identified certain trends in app usage: younger students more often use simple and intuitive applications; middle school students actively use applications for communication and collaboration; high school students prefer applications that help them prepare for exams. During the analysis of responses, it was found that students most frequently mentioned foreign languages and mathematics as subjects they study using mobile applications. This data helps us better understand how students of different age groups use mobile applications for learning.

Among the most popular applications for self-education and entertainment, students named TikTok, Instagram, YouTube, Roblox, Brawl Stars, and Minecraft. Most students use these applications for socializing with friends, watching videos, and playing games. Some students also use applications for listening to music and reading books.

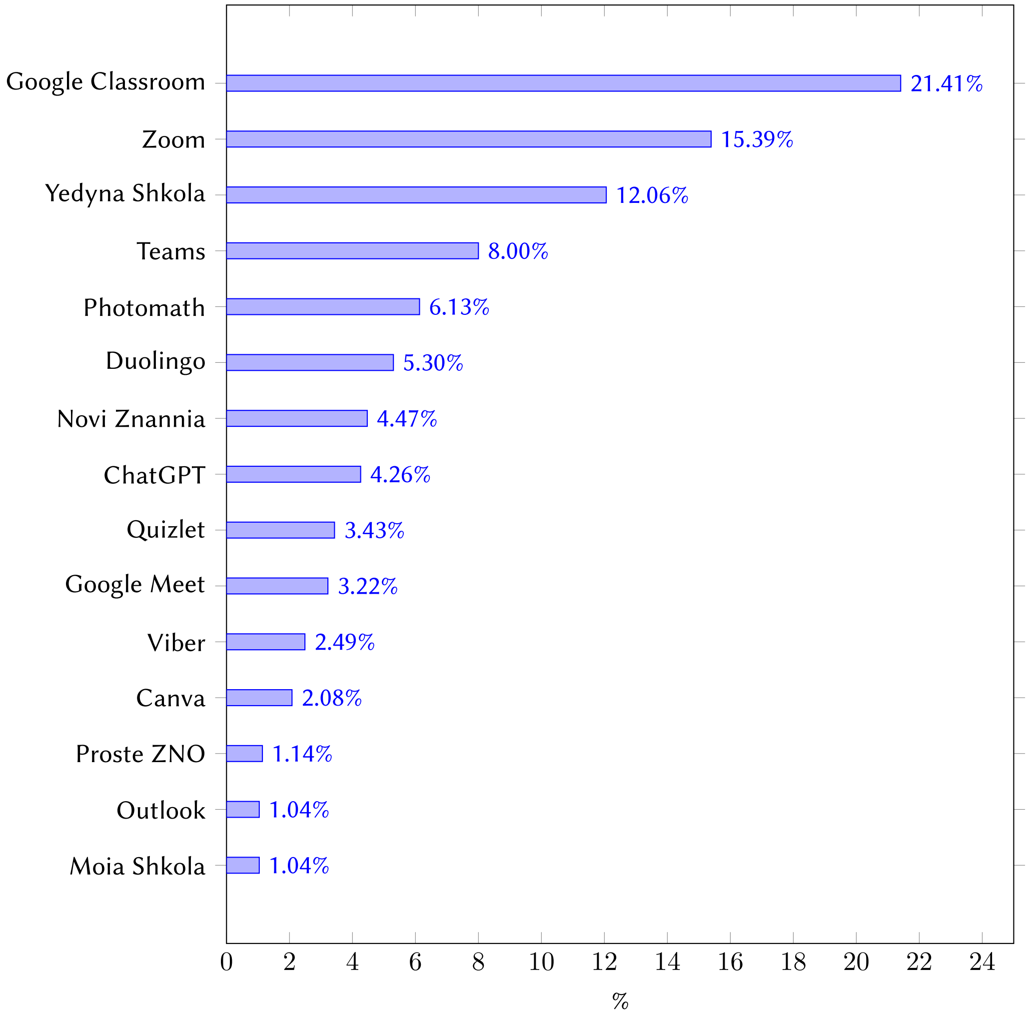

Figure 2: Most common educational apps installed on students' mobile phones.

Most students expressed interest in using educational applications in a game-like format. They believe this could make learning more engaging and enjoyable. Some students even mentioned that they would be willing to use such applications for studying mathematics, physics, chemistry, biology, and foreign languages.

As shown in figure 3, students actively use mobile applications for various purposes, including entertainment, creativity, and communication.

An important factor in the effectiveness of mobile applications is students' attitudes (perceptions) toward gamified content: 70% of students respond positively to the use of mobile applications in the learning process, 20% are neutral, and 10% respond negatively. This indicates the need to consider students' concerns and beliefs when developing and implementing mobile educational solutions.

As established, most students use simulators and interactive tasks to prepare for lessons and assessments. They believe these tools help them better understand the material and improve their knowledge. 60% of students regularly use mobile applications, 30% use them as needed, and only 10% do not use them at all. The most common subjects for which students use simulators are mathematics, foreign languages, and history.

Some of the most popular social networks and messengers among students are Telegram – 90%, Viber – 80%, TikTok – 75%, Instagram – 65%. Most students use them for communicating with friends, exchanging messages, and sharing photos. Some students also use them for learning and sharing educational materials. For example, a student from Khmelnytskyi Lyceum No. 10 uses Telegram to communicate with classmates, while a student from Odesa Lyceum No. 7 uses Viber to exchange

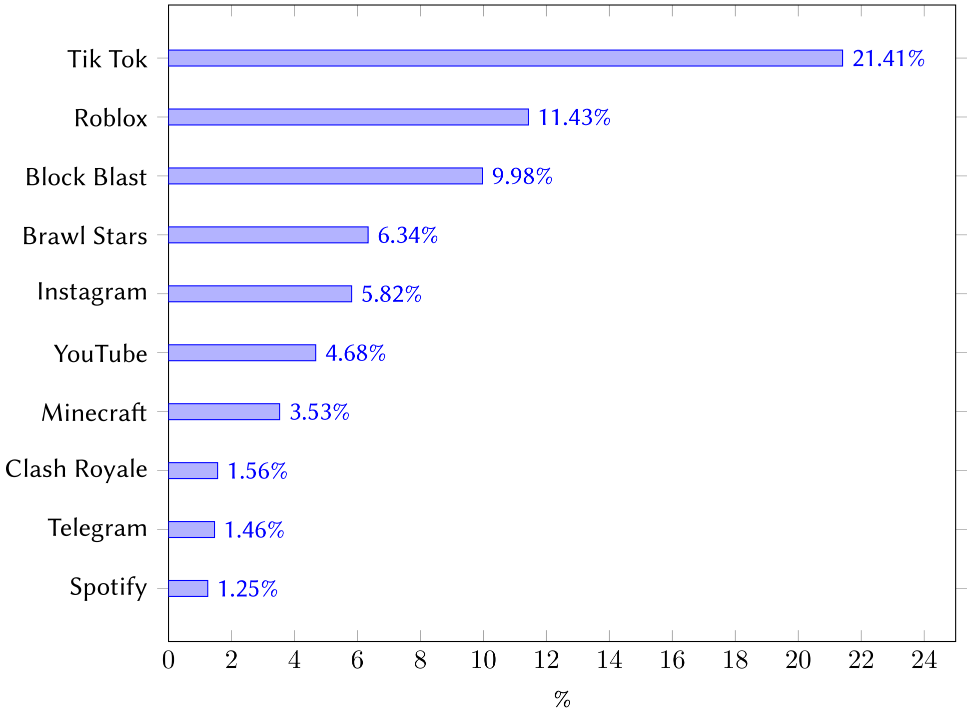

Figure 3: Mobile applications used by students for self-education and entertainment.

messages with friends.

Additionally, the survey found that 95% of students use mobile phones for completing homework, 80% of students believe that mobile phones help them learn better, 70% of students would like to use more educational applications in school, and 60% of students believe that mobile phones help them develop creative abilities (figure 4).

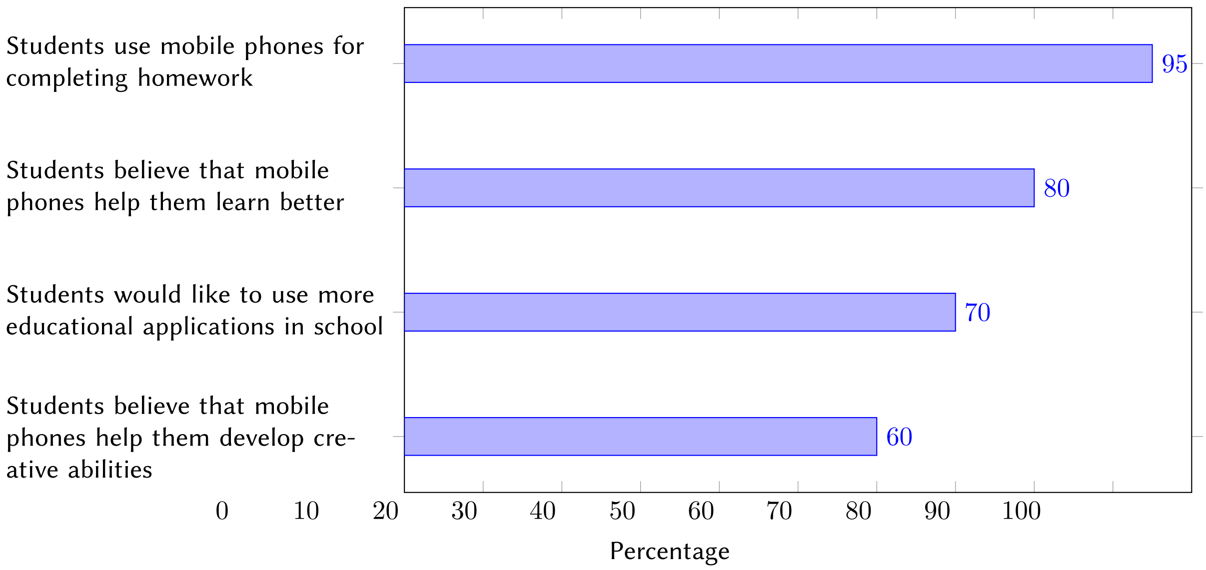

Figure 4: Students' opinion on the use of mobile applications for learning.

Interestingly, 749 students — almost 80% – use the calendar application, highlighting its widespread use for organizing the learning process.

6. Conclusion

Mobile learning is becoming increasingly popular due to the convenience and accessibility of mobile devices. In the context of digitalized education, the use of mobile applications has become an essential element of the learning process, as it allows students to study anytime and anywhere. Our survey, conducted among students, revealed that most of them actively use mobile applications for educational purposes.

Mobile learning has several key features that determine its effectiveness. First, mobile applications integrate elements of gamification and interaction, increasing students' engagement in the learning process. Many students noted that the convenience of mobile platforms helps them better organize their time and effectively manage their studies. Second, mobile learning provides a personalized educational experience. The use of different applications allows students to tailor their learning to their individual needs and proficiency levels. Specifically, they can choose programs for independent study, take tests to assess their knowledge, or interact with classmates through specialized platforms.

One of the most important aspects is access to educational materials at any time. Mobile applications significantly simplify access to courses or textbooks, enabling students to learn regardless of their location. This is particularly valuable during remote or hybrid learning.

Thus, mobile learning is becoming an effective tool for ensuring access to education, overcoming learning losses, and improving the quality of education. Considering the survey results, it can be stated that its potential in Ukrainian schools remains largely untapped. However, with the introduction of new technologies and applications, this process will only continue to gain momentum.

Declaration on Generative AI

The authors have employed ChatGPT 4.5 to assist with writer's block, translate text from Ukrainian into English, and polish sentences.

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Designing a m-learning methodology to study multimedia in secondary school

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Abstract

Despite the widespread perception of smartphones as a source of distraction in the classroom, their growing impact on the educational environment highlights the need for a pedagogically grounded approach to their purposeful use. This paper explores the potential of integrating mobile devices into the learning process in institutions of lower secondary education. A study was conducted to examine the frequency, purposes, and effects of smartphone use during computer science lessons among students in grades 5–9. The findings revealed a high level of students' digital activity and near-universal access to smartphones, contrasted with their limited educational application. A significant discrepancy was identified between the current content of the "Multimedia" topic in the grade 8 computer science curriculum and students' pre-existing digital skills. In response to these challenges, an original teaching methodology for the topic "Multimedia" was developed, incorporating m-learning technologies and the BYOD (Bring Your Own Device) model. The proposed approach emphasizes the use of smartphones for project-based learning activities focused on the creation and editing of multimedia content. Grounded in activity-based and project-oriented pedagogical principles, the methodology is aligned with students' actual digital competencies and takes into account the constraints of wartime educational settings. The approach has the potential to be adapted to other areas of the computer science curriculum or subjects requiring hands-on engagement with digital technologies.

Keywords

computer science, mobile learning, BYOD, multimedia,

1. Introduction

Modern society is increasingly becoming digital. This has a significant impact on all areas of life, including education. Every year, the speed of these transformations forces educators to look for answers to new challenges. For several years now, one of them has been the use of smartphones in education. On the one hand, mobile devices have long been an integral part of students' daily lives. This is especially true now that most Ukrainian schools have implemented a blended learning format due to the Russian invasion [1, 2, 3, 4]. However, the role of these devices in the learning process is still a matter of debate. In many educational institutions, smartphones are viewed primarily as a distraction that negatively affects concentration and academic achievement. This leads to restrictions or a complete ban on the use of these gadgets.

At the same time, pedagogical practice and scientific research demonstrate the significant potential of mobile devices as an effective learning tool. The introduction of technology contributes to the transformation of traditional teaching methods by diversifying the ways of presenting material, increasing student motivation, and engaging them in active learning activities. Smartphones provide ample opportunities for working with multimedia content, performing interactive tasks, conducting research, and creating their own learning projects. Their use is especially relevant when studying topics related to digital technologies. In this study, we will consider the topic "Multimedia", as it is the most controversial. At the current stage of information technology development, most 8th grade students

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already have basic skills in working with multimedia. Children actively use smartphones, tablets and personal computers, and are familiar with the basic functions of creating, editing and publishing photos, videos and sound.

This gives rise to **the research hypothesis** that there is a significant discrepancy between the content of the topic “Multimedia” in the current computer science curriculum for grade 8 and the existing practical competencies and real needs of students, due to their experience of using modern digital devices (including smartphones). This requires clarification of some of the program material of the secondary school computer science course (Ukraine).

This study aims to analyze the current role of smartphones in the educational process, identify their potential as instructional tools, and develop a methodology for their effective use in Grade 8 computer science lessons on the topic of “Multimedia”. There is a considerable amount of research confirming the effectiveness of mobile learning (m-learning). The use of smartphones contributes to the implementation of an individualized approach to learning, the development of independent work skills and the formation of students’ digital competence, which is a key requirement of modern education. Despite these advantages, the widespread use of mobile technologies in schools remains limited due to insufficient methodological development of their use.

2. Potential and challenges of using m-learning in education

Mobile learning (m-learning) is one of the types of distance learning in which the process of accessing learning content using portable devices such as smartphones and tablets provides flexibility and the ability to learn anytime and anywhere [5]. The technical implementation of mobile learning (m-learning) varies depending on its educational objectives – be it microlearning, skills training, collaborative activities, or formative assessment. For example, adaptive platforms like *EdApp* or *Duolingo* are suitable for personalized skill development, whereas tools such as *Padlet*, *Jamboard*, or *Google Workspace* support real-time collaboration.

Regardless of its purpose, a typical m-learning system architecture includes the following core components:

- **Learning Management System (LMS)** or mobile application with a responsive interface;
- **Content storage**, either local or cloud-based (e.g., *Google Drive*, *OneDrive*);
- **Communication tools**, including messaging platforms, video conferencing, and discussion forums;
- **Progress tracking tools**, such as integrated quizzes and activity analytics;
- **User interface** designed following principles of minimalism and digital accessibility;
- **Security mechanisms**, including authentication, access control, content filtering, data encryption, and privacy protection in accordance with child data regulations.

One of the most effective approaches to implementing mobile learning in educational institutions is the concept of “Bring Your Own Device” (BYOD) [6, 7], which is widely used in foreign schools and universities. This model allows students to use their own mobile devices for educational purposes, which contributes to the personalization of the learning process, reduces the cost of purchasing school equipment, and increases student motivation to learn [8]. At the same time, the practical application of BYOD requires solving some challenges [9].

Recent international studies confirm the effectiveness of using mobile applications and tablets in early childhood and primary education, particularly in teaching science and mathematics [10, 11]. In Ukraine, mobile learning is gradually being introduced at all levels of education, from pre-school to higher education, ensuring the continuity of the educational process and increasing its efficiency. This is especially true in times of war, when traditional forms of education may not be available. The use of mobile technologies allows students and teachers to adapt to these challenges. At the school level, mobile technologies are actively used in both distance and blended learning formats. One of the key projects is the All-Ukrainian Online School [12]. It provides students in grades 5-11 with access to educational materials through mobile devices. Initiatives are also being implemented to support children in crisis. For example, primary schools use mobile applications such as "Can't Wait to Learn" to help children learn math and reading even in bomb shelters [13].

University education also actively integrates mobile learning into the educational process by developing new methods [14]. At the same time, mobile applications are widely used to teach Ukrainian as a foreign language at medical universities [15]. It demonstrates the effectiveness of digital technologies in specialized education. In addition, smartphones are becoming an essential tool in scientific activities [16, 17].

Based on the above facts and analysis of scientific sources, we will highlight the advantages of mobile learning, such as

1. Mobile devices, as an important client component of cloud technologies, provide access to educational resources anytime, anywhere [18]. This is especially important for students in remote areas or with limited access to educational materials [19].
2. Multimedia content and interactive technologies increase the effectiveness of learning [20, 21, 22, 23, 24]. Educational applications, virtual simulations, and gamified quizzes make complex concepts more visual, promote a deeper understanding of the material, and increase student motivation [25].
3. An important advantage of mobile learning is uninterrupted communication between students and teachers. Thanks to messengers and collaboration platforms, children can get advice, work on projects, and participate in discussions [26]. Mobile learning can foster a sense of connection and community for children studying remotely [27].
4. Adaptive educational applications that use artificial intelligence algorithms allow for personalized learning, taking into account the individual needs and pace of each student [28, 29, 30, 31]. If a student has difficulty understanding a certain topic, the app can offer additional materials or tasks to consolidate knowledge. It also facilitates learning for children with special educational needs [32].
5. Mobile learning contributes to the development of digital literacy. It is essential for successful integration into the modern digital society. Students who actively use mobile technologies in their learning acquire skills in working with digital tools, analyzing information and critical thinking [33].

However, many scholars also discuss the challenges of this learning format. Among them, we can distinguish the following themes.

- Cell phones are a significant distraction during school, negatively impacting academic performance. Multitasking leads to lower test scores and memory impairment [34].
- Unequal access to the Internet and devices creates a digital divide, especially in rural areas. This exacerbates educational inequalities by limiting students' opportunities [35].
- Mobile phones can be used for cyberbullying and the dissemination of inappropriate content. There are risks to data privacy [36].
- Teachers lack the expertise to use mobile technologies effectively. Many are wary of this type of learning [37]. Therefore, it is advisable to introduce effective models for training future and retraining practicing teachers.

3. Development of a methodology for studying the topic "Multimedia" based on m-learning

As the above studies show, mobile devices are widely used by students in everyday life. However, their potential as a learning tool remains underutilized [38]. This is especially true for teaching computer science, where a significant number of topics related to digital technologies can be effectively supplemented by mobile applications [39]. One of these topics is "Multimedia". It is currently taught in 8th grade in Ukrainian schools. The curriculum involves familiarizing students with digital images, audio and video files, their formats, processing principles, and the use of appropriate software. The traditional approach emphasizes the use of desktop computers, while modern mobile devices already contain built-in tools for working with multimedia. This opens up the possibility of creating an interactive and practice-oriented learning process that can be implemented even in schools with limited technical equipment. Before developing a methodology for teaching the topic "Multimedia" in grade 8, a study was conducted to identify the current state of use of mobile devices in the educational process and to determine effective approaches to their integration into computer science education. The study used methods such as analysis of curricula and textbooks, observation of the actual learning process, student surveys, and statistical methods for processing questionnaire data.

3.1. Study of the impact of smartphones on the educational process

To identify the current problems, a questionnaire was developed that included general data collection (age, gender, smartphone ownership, etc.), educational aspects (use of smartphones in general and in computer science classes, self-assessment of distraction, etc.), and the current level of knowledge on the topic of Multimedia. The results of the survey are available at the link https://docs.google.com/spreadsheets/d/1bo5i6BB21MoAksytIK2zjJd1AMFUo_FYWsC7OREiaoI.

The survey involved 202 students (Ternopil district, Ternopil region, Ukraine), with an average age of 12.46 years, mode and median of 13. All respondents study at a basic school (grades 5-9). The availability of smartphones among students is almost total (99.5% of students have their own device). Two participants reported that they were only allowed to use a smartphone at home. Despite this, almost all respondents have access to mobile devices, which creates potential opportunities for their use in the educational process. Diagram (figure 1) shows that only 6% of students use a smartphone for less than 1 hour a day. In addition, smartphones are ranked first in terms of daily use (98.5%). This shows that this device plays an important role in children's lives. The second and third places are taken by laptops and personal computers. We believe that students use these devices for more complex tasks that require larger screens and multitasking.

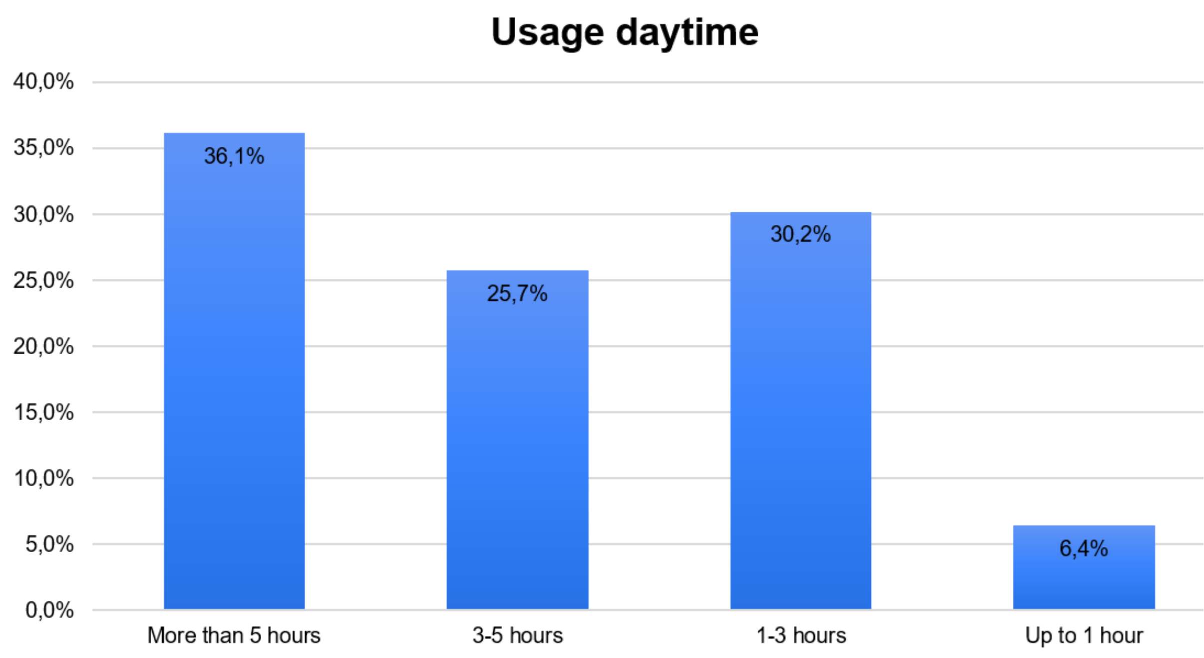

Figure 1: Time students use a smartphone during the day.

We analyzed the purposes of using smartphones by students in each of classes (table 1).

Table 1
Frequency of using smartphones.

Grade	Social networks	Study	Games	Content creation	Watch videos	Listening to music
5	0.906	0.406	0.563	0.344	0.750	0.750
6	0.667	0.500	0.548	0.262	0.619	0.619
7	0.943	0.543	0.629	0.286	0.657	0.657
8	0.880	0.580	0.580	0.340	0.640	0.640
9	0.860	0.442	0.674	0.326	0.698	0.698

The table 1 shows that the most respondents use smartphones for social networking. Only the 6th grade shows a moderate frequency of this choice. Also, everyone who uses a smartphone to watch videos also uses it to listen to music.

The next stage of the analysis was to study the use of smartphones in the educational process. Based on student responses, a rating of the most used apps was compiled. NaUrok was the leader among students' responses, with 78.2% of them choosing it, and Vseosvita with 49.5%. These Ukrainian services specialize in online testing in various subjects. Thus, we can say that students most often use smartphones for educational purposes to take tests. This is also confirmed by the histogram of smartphone use in computer science classes (figure 2). According to this histogram, taking tests and searching for information are the two main and most obvious uses of smartphones.

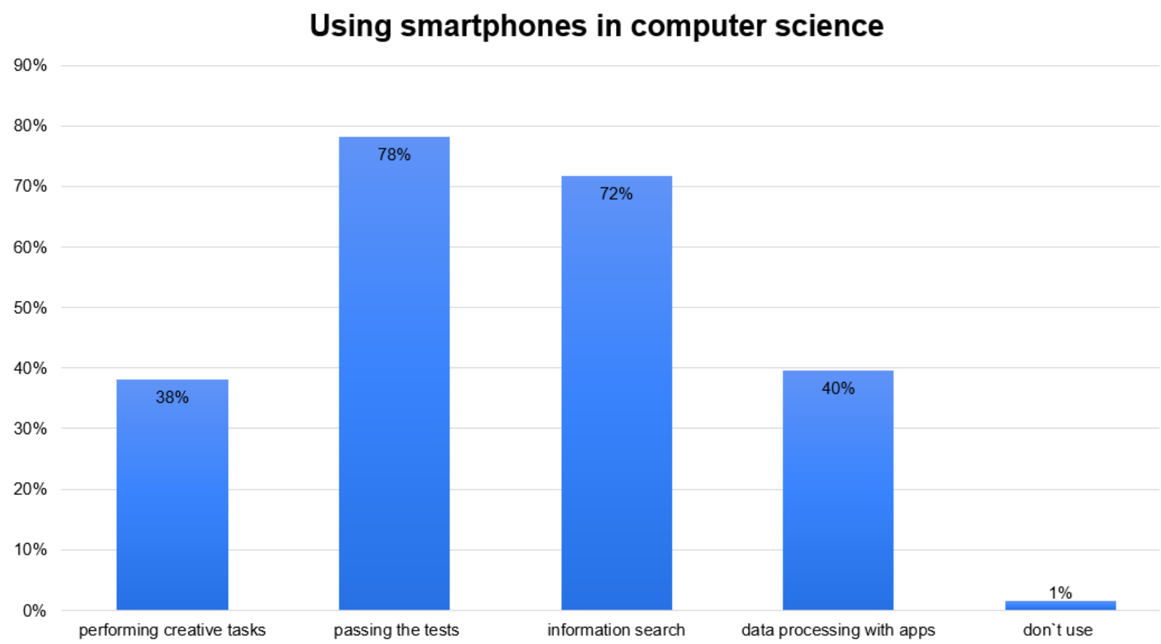

Figure 2: Using smartphones in computer science lessons.

To assess statistically significant differences in smartphone use policies among students of different grades, χ^2 tests and analysis of adjusted residuals were conducted. The following χ^2 test results were obtained $\chi^2 = 36.17$, p-value = 0.003 for degrees of freedom df = 16. This allows us to accept the alternative hypothesis that a relationship exists between class and permission to use smartphones in education. Additional Cramer's V was used to determine the strength of this relationship (effect size). Its value of 0.212 indicates a weak relationship.

To determine in detail the impact of each of the indicators of policy ("All", "All except control", "Several", "Only in computer science", "Not allowed at all"), the analysis of adjusted residuals was used.

The results were visualized using a heat map (figure 3).

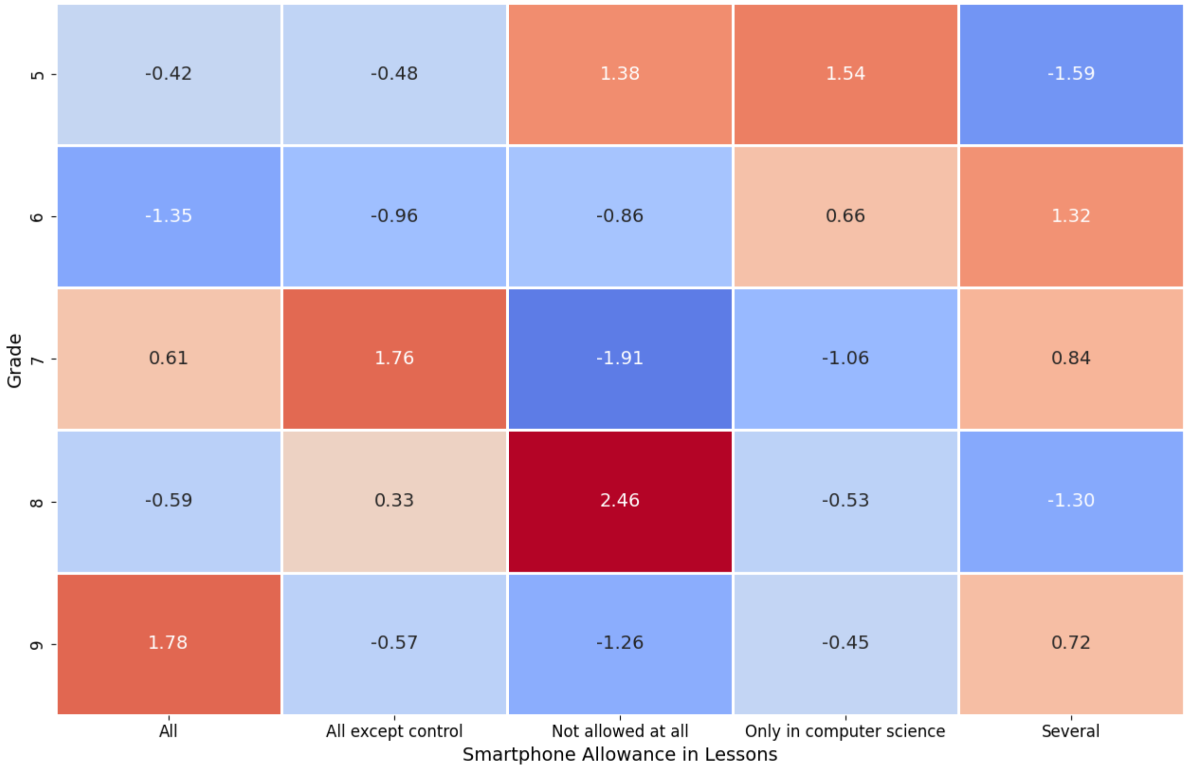

Figure 3: Heatmap of adjusted residuals (significance in smartphone allowance by grade).

In it, the numerical values of the residuals reflect the deviation of the actual number of responses from the expected number under conditions of random distribution. In other words, the heat map shows how the rules (policies) for using smartphones change from junior to senior high school. Positive (red squares) values indicate that the value of the indicator exceeds the expected value, and negative (blue) values indicate a decrease.

Analyzing the heat map (figure 3), we conclude that in the lower grades there is a higher level of outright bans on smartphone use, which is weakened by grade 7. However, this policy is not observed in grade 8. This is due to a strong positive residual for the indicator "Not allowed at all" (+2.46). Then, in grade 9, the trend toward a decrease in the total ban on smartphone use continues. Similar nonlinear fluctuations in residuals are observed for the indicators of full permission and use in several or control lessons.

These results can be explained by the fact that the surveyed students study in different schools with different policies on smartphone use. Therefore, children have different experiences of using smartphones in learning, which is confirmed by statistically significant differences in the results. Even within the same school, teachers of different parallel classes have different approaches to the use and control of digital devices, due to the lack of an approved unified policy on the rules of their use. In addition, students have different experiences with smartphones, which also affects their answers to this question.

Another factor that influences the results is the New Ukrainian School. It is the reform that is currently underway in Ukraine. Students in grades 5-7 are now studying under it. One of the key provisions of the reform is the implementation of interactive tasks for which children use smartphones and increasing the autonomy of using a smartphone with each class for students. As can be seen from the heat map (figure 3), there is a connection between classroom and smartphone use permissions in computer science classes. It indicates a certain consistency within our sample of the requirements of teachers who teach computer science in different schools and grades.

The next task is to study the level of distraction from smartphones during studying. Analyzing the questionnaire data, we conclude that almost half of the students (47.5%) claim that smartphones do not affect their concentration during studying, while 3% constantly feel that gadgets prevent them from concentrating. We also analyzed the impact of the classroom on the level of distraction. The calculated value of the $\chi^2 = 11.46$, $p = 0.490$ shows no relationship between class and distraction. This is also evidenced by the graphical representation (figure 4). The chart shows a tendency to increase ("sometimes" in grades 6 and 7) or decrease the frequency of distraction by smartphones ("sometimes" in grades 7 and 8) with the increase in grade level. Lower grade students (5th grade) are more likely to report that they are never or rarely distracted, while upper grade students (8th and 9th grade) are much more likely to report that they are rarely or sometimes distracted.

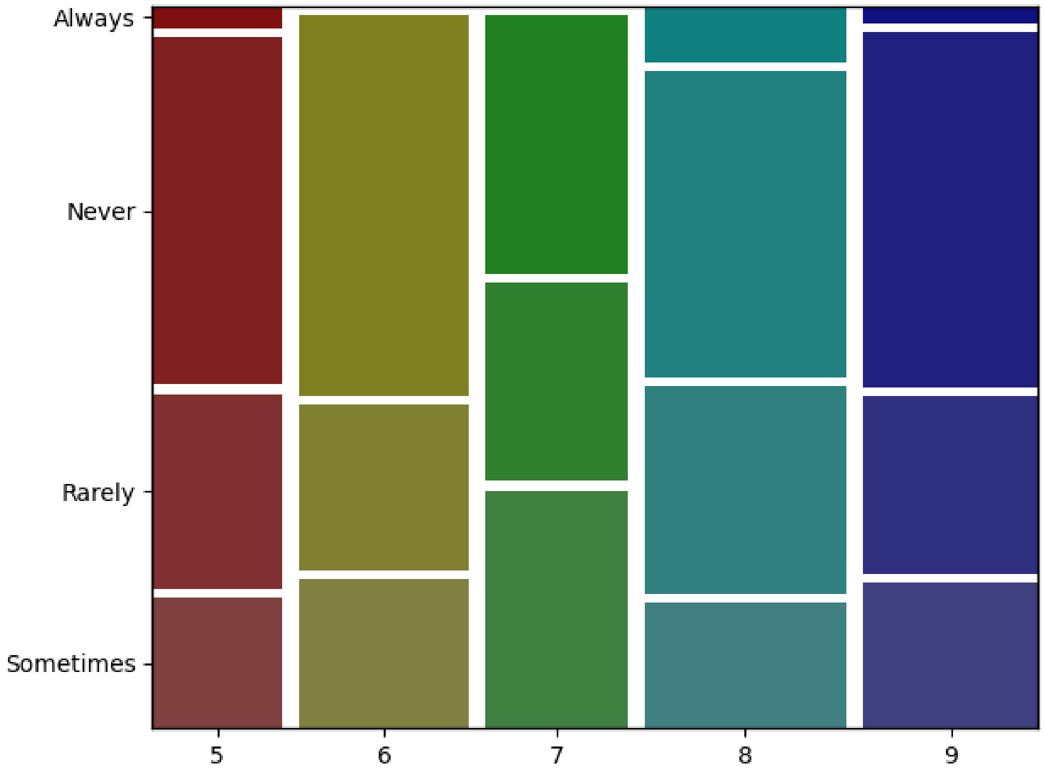

Figure 4: Ratio of student distraction levels at each grade.

At the same time, the category "always" remains the least common answer for all age groups represented in the graph. These results can be explained by the fact that students are generally not inclined to recognize their "addiction" to gadgets. In our opinion, a separate study is needed to investigate this effect.

A scatter plot (figure 5) was created to test the relationship between the level of distraction and the frequency of smartphone use in computer science classes. We transformed the answers to the question "How often do you get distracted in class?" into a numerical format (0 – "never distracted", 3 – "always distracted").

The figure 5 shows that the highest level of distraction is observed in the group of students who use smartphones "Very often (every lesson)". The average distraction rate for this group is the highest (M = 1.22) compared to the others. Gadgets have the least impact on the students who use them once a month (M = 0.55). The groups of students who use smartphones "Often (every second lesson)" and "Sometimes (2-3 times a month)" showed intermediate average levels of distraction (M = 0.84 and M = 0.78, respectively). The variability of responses in these groups was also significant (ranges 0-2 and 0-3, respectively), although somewhat less than in the "Very often" group. Summarizing, we conclude that there is a positive relationship between the frequency of smartphone use in computer science classes and the level of overall distraction. This phenomenon may be due to the lack of proper

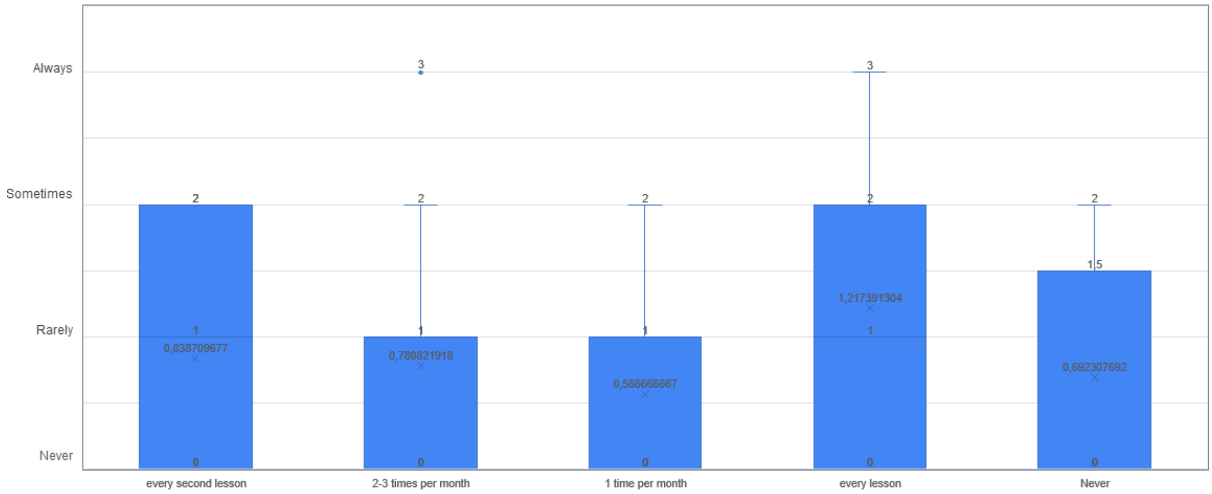

Figure 5: Ratio of student distraction levels in each classroom.

Table 2
Self-assessment of students' multimedia skills.

Grade	Finding an idea	Scenario writing	Shooting video clips	Trimming video	Adding animation	Adding transitions	Adding text	Creating video intro	Recording audio	Applying sound effects	Nothing of this
5	0.656	0.500	0.438	0.688	0.500	0.563	0.750	0.219	0.438	0.344	0.094
6	0.619	0.405	0.476	0.810	0.524	0.381	0.810	0.333	0.524	0.548	0.048
7	0.571	0.371	0.400	0.886	0.571	0.543	0.943	0.343	0.600	0.657	0.029
8	0.680	0.380	0.520	0.860	0.620	0.600	0.840	0.420	0.620	0.800	0.160
9	0.791	0.442	0.465	0.884	0.465	0.605	0.814	0.442	0.581	0.512	0.047

organization and control over the use of smartphones for educational purposes. As you can already see from figure 2, the most common ways to use smartphones are to take tests and search for information. These activities usually take different amounts of time for different students, and if the tasks are set incorrectly, it is quite common for some children to have already completed the task and spend time at their own discretion. This is confirmed by the significant variability of indicators in the "Very often" category.

The third part of the questionnaire included the experience of using smartphones specifically for creating/editing multimedia. Since this topic was chosen because of the hypothesis that the content was not relevant, the Ukrainian State Standard and curricula were analyzed before developing the questionnaire. On this basis, the expected outcomes of this topic were identified, such as building a video sequence, cropping individual elements, adding transitions and simple animations between video fragments, adding text, recording sound, changing the length of an audio track. The frequencies of answers to the questionnaire about students' mastery of these skills are shown in table 2.

According to the table, we see that in most areas, students' awareness of the stages of creation increases in each grade. However, if we consider separately the 7th grade (these students have not yet studied this topic at school) and the 8th grade (students who took it less than 2 months ago), it is noticeable that the increase in values is very small, or absent altogether. This is especially noticeable in the areas of trimming videos and adding text. At the same time, the positive increase is very evident in the area of shooting video fragments, applying effects and searching for ideas. We believe that children tend to choose these answers more often due to attempts to use these skills in computer science lessons. Most teachers ask to use their own video and sometimes audio fragments as evidence that this is really the student's work. Adding simple video fragments is part of the expected skills according to the current curriculum, and the search for ideas, as can be seen, is also growing in the 9th grade, so we assume that this variable depends not so much on the specific computer science lessons as on the involvement of students in school parliaments, the school press and in general the general activity of students and their inclusion in various spheres of social, cultural and personal life. The fact that approximately 16% of 8th grade students after completing this topic claim that they do not have any of the listed skills is also thought-provoking. The lack of motivation of 8th grade students for this course after studying it is also evidenced by the highest rate of the answer "Not at all interesting" among all grades to the question about interest in studying this topic (figure 6). Considering this figure, we can assume that this is due not so much to students' awareness in this area as to the lack of motivation to study due to previous experience.

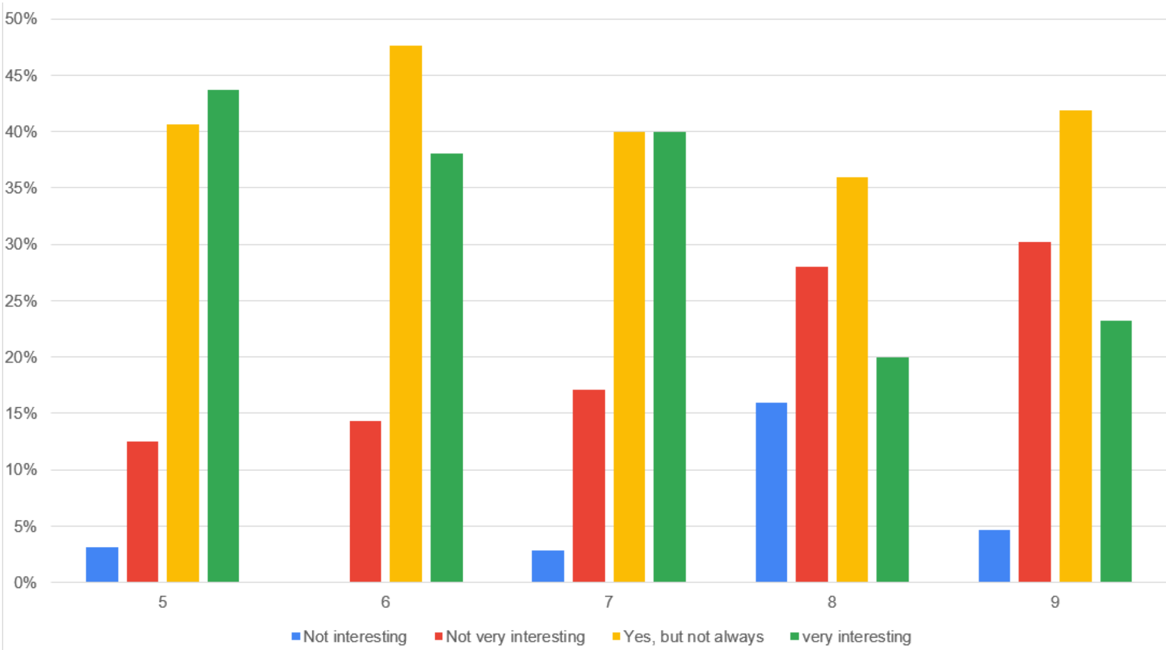

Figure 6: Student interest in learning multimedia.

To study in more detail the impact on students' interest in learning multimedia, regression was used as a method of analyzing the questionnaire data. In this case, interest in learning the topic was considered as a dependent variable, and class, use of smartphones in computer science lessons, and previous experience of using them were independent variables. We used linear regression. In it, all variables were transformed to numeric as follows:

- interest_ordinal from "Not interesting" is 1 to "Often" is "very interesting";
- experience_ordinal from "No" is 1 to "Often" is "3";
- using_CS_ordinal from "Never" is 1 to "every lesson" is "6".

The tidyverse library of the R language was used to build a linear regression. A summary of fitting linear models is given in table 3.

As can be seen from table 3, there is a positive effect of the frequency of smartphone use in computer science lessons on students' interest in learning multimedia. For example, an increase in the frequency of using a smartphone by 1 unit on the nominal scale of the independent variable using_CS_ordinal results in an increase in interest by 0.067 units on the ordinal scale of the dependent variable. This value is relatively small. We can assert a statistically significant, albeit small, effect of this factor.

Table 3
Summary fitting of liner model.

	Estimate	Std.Error	P-value
using_CS_ordinal	0.067	0.032	0.042
experience_ordinal	0.015	0.087	0.862
grade	-0.177	0.045	0.000

As the second row of the table shows, there is no significant effect of students' experience with video editing on their interest in learning multimedia. The reason for this may be the fact that students' interest in learning multimedia is driven by other factors (desire to get a good grade, to go to university) rather than by previous experience with smartphones. The third row of the table shows the negative effect of the class factor on interest. That is, for each increase in the class number, interest decreases by about 0.18 units on the scale of the interest_ordinal variable. Despite the overall significance ($p < 0.001$) of the multiple $R^2 = 0.080$ model, the summary shows that only 8% of the variance of the dependent variable is explained by the selected factors. This is a rather low figure, indicating limited predictive power. Other unmeasured factors (e.g., teaching style, peer influence, access to tools, etc.) may have a greater impact on student engagement as well.

To visualise the regression model, a graph of the dependence of predicted interest on the frequency of smartphone use in computer science lessons for each class (figure 7).

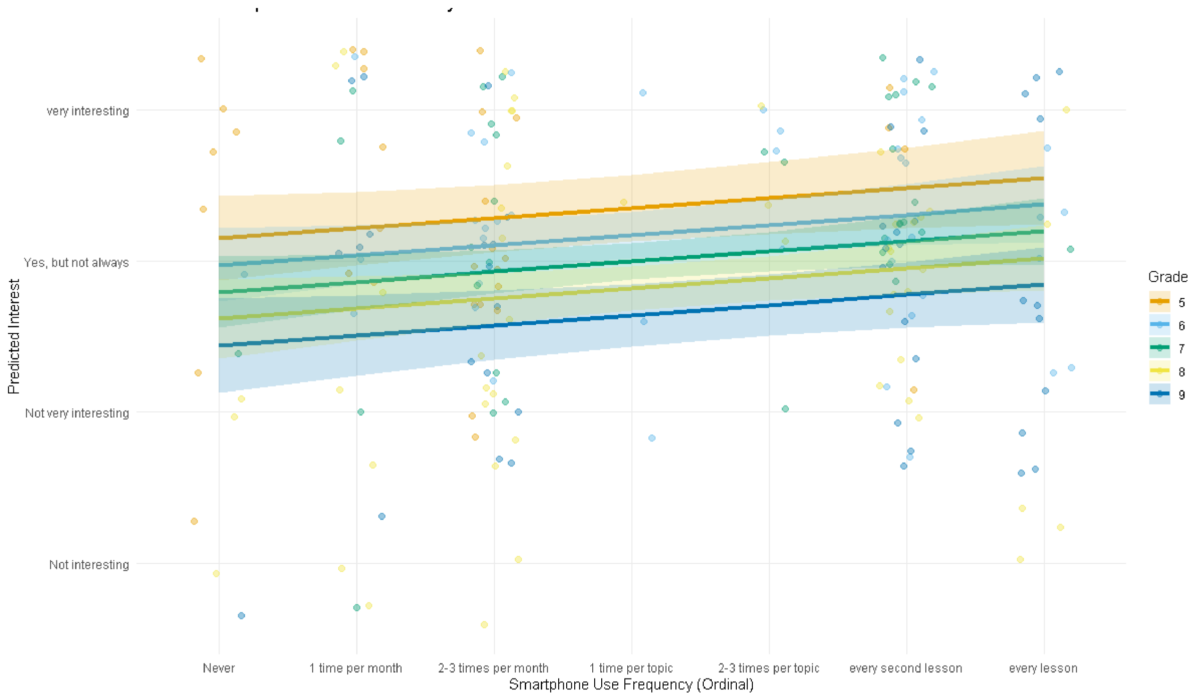

Figure 7: Effect of smartphone use on interest by grade.

As can be seen from figure 7, all of the level lines have a slight upward slope. This indicates that more frequent smartphone use in computer science lessons is associated with a slightly higher interest in multimedia learning. Students in grade 5 (orange line) show the highest predicted interest in learning across all measures of smartphone use. Grade 9 students (dark blue line) typically have the lowest predicted interest. The graph is consistent with the regression model, in which grade has a negative coefficient (older students show lower predicted interest). The lighter shading of the areas adjacent to the lines indicates some uncertainty in the model. The intervals widen somewhat in extreme cases (e.g., for the indicators "Never" or "Every lesson"). This uncertainty indicates a small number of respondents who chose an extreme value. The figure also shows outliers related to students in grades 8-9, who indicated a high level of smartphone use but a low level of interest in learning multimedia. In general, the scatter plot and regression lines indicate that neither the "frequency of use" nor the grade are reliable predictors of interest in learning multimedia.

3.2. Development of a methodology for studying the topic "Multimedia"

The analysis of the current 8th grade computer science curriculum and the results of the survey revealed a significant discrepancy between the expected goals of studying the topic of "Multimedia" and the educational needs and actual level of digital literacy of modern students. In order to overcome the identified contradictions and increase the effectiveness of learning, an alternative teaching methodology was developed that does not reject the requirements and goals of existing curricula, but changes the approaches by which they are achieved. The methodology is based on the principles of an activity-based approach [40], project-based learning [41], universal learning design [42], and the integration of mobile learning technology [43, 44, 45, 46, 47]. The pedagogical feasibility of the proposed methodology is to shift the emphasis from reproducing technical operations to developing key competencies in a context close to real-life situations and potential interests of students. Based on these data, we developed each lesson's purpose, expected results, and general plan (table 1). Most class time (about 75%) is spent on practical skills. Unlike performing isolated exercises, students work on creating a comprehensive multimedia product (short video narrative, training videos using scribing, audio works). Work on the project includes all stages, from generating an idea and writing a script to shooting/recording, editing, and post-production. Studying this topic aims to develop students' key and subject competencies by familiarizing them with the basics of working with multimedia technologies and developing skills in their practical application for creating, editing, and presenting multimedia content.

The table 4 contains components of the methodology we have developed for using mobile technologies in teaching the topic "Multimedia".

Table 4: Component of authors' methodology.

#	Lesson topic	Summary	Forms of organization	Methods	Tools	Knowledge Test
1	Definition of multimedia, their importance in the modern world	Types of video files, their formats, features of use. Overview of video editors. Analysis of common mistakes in video works.	Frontal (discussion, demonstration), Group (video analysis), Individual (completing test tasks, registering on platforms)	Discussion, problem-search method, demonstration, analysis of examples	Web page, video with examples of errors (YouTube)	Practical analysis of errors in videos, search for information about basic video requirements, reflection (discussion of the importance of the topic). GR1, GR4.
2	Basics of creating video works	Learn how to plan an idea for a video. Features of shooting for different purposes (blogs, presentations). The basics of shooting on a smartphone (camera settings, lighting). Search for copyright-free videos.	Frontal (discussion, explanation), pair work (video shooting), group reflection (analysis of classmates' videos)	Explanatory and illustrative (demonstration of examples), interactive (discussion, self-assessment), problem-search (video analysis), practical (video shooting).	Web page, Video snippets for demonstration, Wordwall, smartphone cameras	Self-assessment and analysis of videos, determination of emotions by viewers, discussion of the choice of technical settings. GR2, GR3.

3	Installation basics	The main tools of the video editor. Working with video fragments: cropping, applying effects, transitions. Use of UGC content and copyrights.	Frontal (analysis of video instructions), group work (video creation), presentation of works (analysis and evaluation)	Inverted class, explanatory and illustrative, practical.	Web page, video instructions, video editor, school supplies (objects for video review)	Presentation of ready-made videos, self-assessment and mutual evaluation according to criteria, discussion of difficulties in work
4	Audio in multimedia	Sound recording basics: types of microphones, features of sound recording for video. Overview of sound editors. How to record clear sound at home. AI as one of the ways to create sound.	Frontal (explanation, demonstration), group (creating audio fragments), individual (working with audio effects)	Demonstration (microphones, AI generators), practical (audio creation and editing), partial search (audio quality analysis), project (creation of a joint product).	Web page, Microphones (if available), online voice generation services, VN editor (to add audio effects)	Self-assessment of recording quality, presentation and analysis of the created audio fragments, discussion of the choice of dubbing methods
5	Scribing as a method of explaining complex concepts	The concept of scribing, its meaning. Text and audio visualization.	Frontal (explanation, demonstration), Individual (work in Canva)	Demo (scribing samples), practical (video creation)	Canva webpage, service or app, Audio recordings from the previous lesson	Presentation of finished works, Self-assessment of the quality of scribing
6	Project activity: development of a video idea	Forming groups, discussing ideas for video projects, creating scripts.	Group work. GR1	Project method, brainstorming	Smartphones, online documents, video editors, audio and video files	Comprehensive project assessment according to the established requirements
7	Project activity: shooting	Shooting video materials for projects, using multimedia technologies.	Practical work. GR4.	Observation method, exercise method	Smartphones, online documents, video editors, audio and video files	Comprehensive project assessment according to the established requirements
8	Project activity: installation	Video editing, adding sound, effects, titles.	Practical work. GR3	Project method, interactive method	Smartphones, online documents, video editors, audio and video files	Comprehensive project assessment according to the established requirements

9	Completion of the project. Publishing videos on streaming platforms	Completion of projects, preparation for presentation.	Practical work. GR3	Project method	Ready-made video projects, YouTube service	Comprehensive project assessment according to the established requirements
10	Project presentation and thematic evaluation	Presentation of projects, evaluation of works. Reflection: what you learned, what tools were the most interesting.	Group work, presentation. Comprehensive work on all 4 groups of results.	Method of reflection, method of mutual assessment	Multimedia projects of students, projector	Comprehensive project assessment according to the established requirements

The assessment of academic achievements has also undergone changes. Starting next year, eighth-graders will study according to the New Ukrainian School reform. Therefore, in this methodology, we focus on assessment by groups of results. Instead of assessing only the final product, we use a comprehensive approach that considers the development of student competencies at different stages of their work on the project. The practical tasks that students perform during the lessons are divided into the groups of outcomes that students develop during practical work, and an assessment table has been designed for project activities (table 5). This table is also available to students as a guide to the main requirements for the activity.

Table 5
Criteria for assessing students' learning achievements according to the author's methodology.

Evaluation criterion	Score
GR1. Works with information, data, models.	
The scenario of the video is logically structured, has an introduction, a main part and an ending.	2
The created scenario is based not only on selected fragments of the text, but also on your own thoughts on the topic. In the video, the student not only expresses his opinion, but also confirms it with scientifically proven facts.	2
GR2. Creates information products.	
All technical aspects are done with high quality (correctly adjusted video contrast, lighting, framing).	2
Editing effects are appropriate, they emphasize the overall mood of the video.	2
It is advisable to use animation elements, displays, stickers, etc. to emphasize the narrative.	1
GR3. Works in a digital environment.	
The student can explain all the stages of video creation, disassemble the finished project into separate frames, explain what editing techniques should be used to achieve a certain result.	2
A student can complete all of the above steps.	3
GR4. Safely and responsibly works with information technologies.	
All data used in the video has a verified source.	1
All videos used in the video are created by the child, or uploaded without copyright infringement.	1

The next step in developing the methodology was to select the learning tools. Although the methodology focuses on the use of smartphones, and their use is almost ubiquitous, not only applications but also services accessible from any device were chosen to ensure that the principles of the UDL are implemented. The following criteria were taken into account:

- availability for both iOS and Android systems;
- possibility of online and offline use;
- easy navigation;

- free access to the functionality;
- no ties to the occupying country and the absence of the developer in the list of sanctioned organisations in Ukraine.

VN as an application and Vimeo as a service were selected as video editors. Among the audio editors, we selected the voicegenerator.io service and the Video Voice Changer app. These resources were chosen because they have the ability to change the voice and this is the feature that children will use. Canva was chosen as a tool for creating scribbles, both as a service and as an application, because children are familiar with its functionality and can focus on the process of creating.

The next step was to develop the content of the course such as theory, interactive tasks, instructions for practical work, video work, etc. (figure 8).

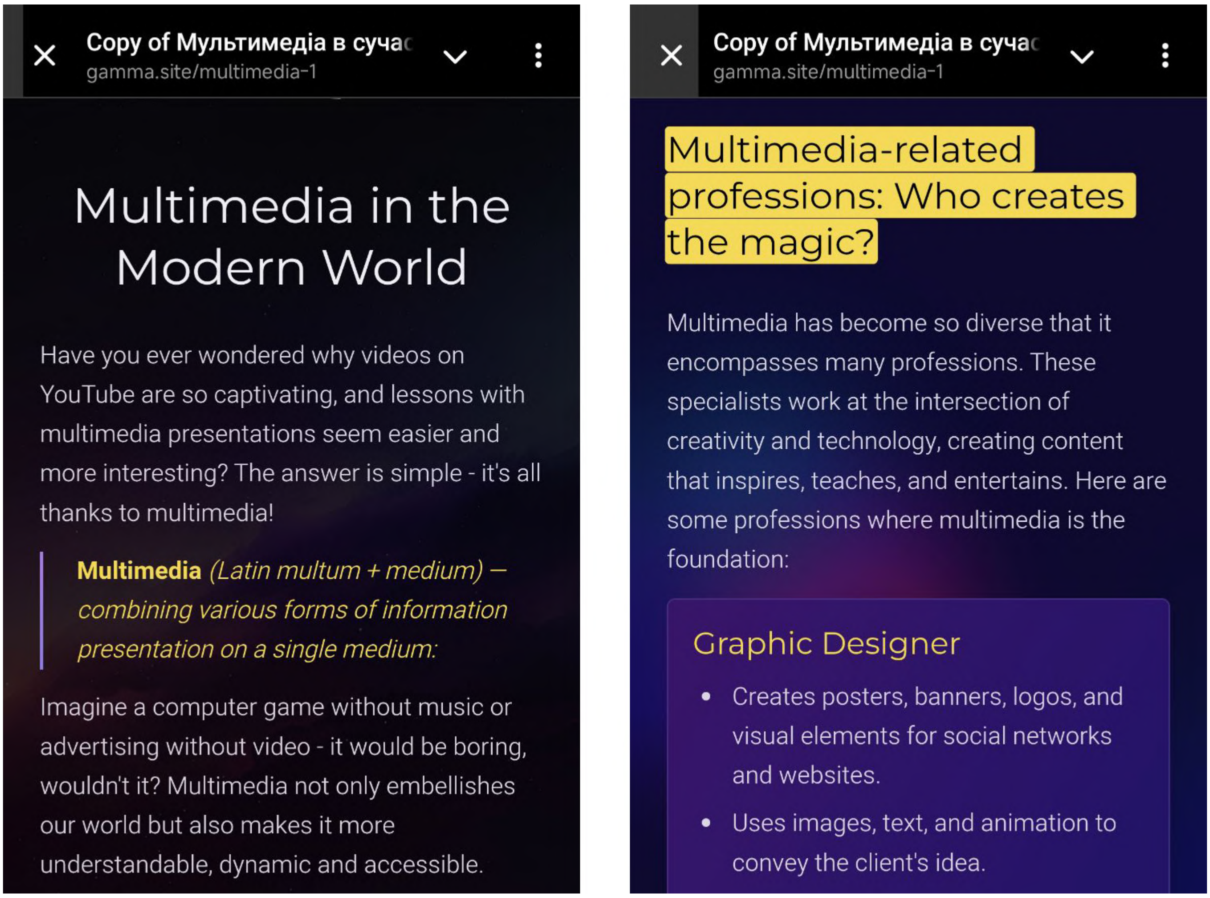

Figure 8: Learning material on a student's smartphone screen.

As many studies have already confirmed, modern learners have difficulty perceiving educational material that is presented orally or in text format. Therefore, it is important to use different types of information presentation. Since this topic focuses on the study and use of multimedia, it is a good approach to use different types of media. In this case, in addition to information about this area, children will receive real examples of application. The central element of the methodology is the 'flipped classroom' model, which optimises the use of class time. Instead of a traditional lecture, students work on the theoretical block outside the classroom using specially prepared training materials posted on the website. These materials are developed with the principles of universal design thinking in mind and are presented in various formats: short video lectures explaining key concepts (e.g. framing, editing transitions); interactive web pages with textual explanations, illustrations and examples; links to external resources. This allows students to work at their own pace and the teacher to devote classroom time to hands-on activities and individual advice.

Modern web page editors make it as easy as possible to organise information and create interesting material without any additional skills. One of these options is the Gamma service, which we chose because of its interactive features and the availability of templates that greatly simplify content structuring and ensure quick adaptation to changes. The main focus was on visual consistency and logical presentation of the material, which allows students to navigate the information better using the blocks. Another advantage is the correct display of the webpage on different devices, including smartphones and PCs (figure 8 and figure 9).

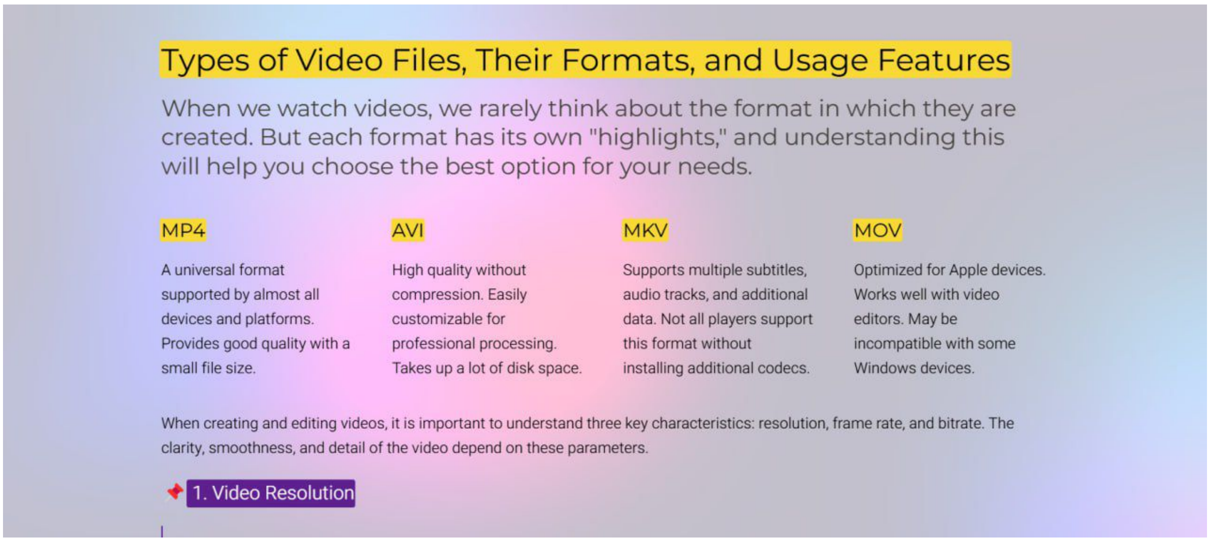

Figure 9: Learning material created with Gamma.

4. Conclusions

The study confirmed the relevance of the problem of integrating mobile devices into the educational process of secondary education and revealed significant shortcomings of the traditional approach to studying the topic of "Multimedia" in grade 8. The analysis of the curriculum and the results of student and teacher questionnaires revealed a gap between the content of education, which often focuses on outdated or already mastered technical skills, and the real needs and interests of modern students. The developed and theoretically substantiated methodology for studying the topic "Multimedia". The technical implementation of the methodology is based on an adapted mobile learning (m-learning) architecture that incorporates the BYOD model. Google Classroom was used as the LMS, providing access to assignments, instructions, and student submissions. Theoretical content was delivered through the Gamma platform, which supports multimedia content, visual consistency, and optimization for mobile devices. Learning materials and student projects were stored on Google Drive (for private interaction within the Google Classroom environment) and published via YouTube, which ensured convenient access and a variety of content formats. The proposed approach has a number of key advantages. In particular, it helps to increase the relevance and motivation of learning by shifting the focus to the practical application of multimedia technologies, introducing modern professions and using mobile devices familiar to students. The effective organisation of the learning process is achieved through the 'flipped classroom' model, which frees up time for active practical work. In addition, important advantages include ensuring individualised learning through the application of UDL principles and bridging the gap between formal education and students' informal digital experience by using their existing smartphone skills as a basis for further development. At the same time, the successful implementation of the methodology requires consideration of potential challenges, such as the development of students' self-organisation skills and adequate methodological and technical training of teachers. The primary task of further work is to experimentally test the developed methodology in real-life conditions of Ukrainian schools to quantify and qualitatively assess its effectiveness compared to traditional teaching. In addition, it is advisable to explore the possibilities of adapting the proposed approach to study other topics of the computer science course or other subjects.

Declaration on Generative AI

While preparing this work, the authors used ChatGPT by OpenAI to rephrase and improve their own text. Google Gemini was also used to search for relevant literature. All content generated with the assistance of AI tools was reviewed and edited by the authors, who take full responsibility for the article's final version.

Author contributions

Conceptualization, Vasyl P. Oleksiuk and Julia A. Overko; methodology, Vasyl P. Oleksiuk; software, Vasyl P. Oleksiuk and Julia A. Overko; writing – original draft, Julia A. Overko; writing—review and editing, Vasyl P. Oleksiuk. All authors have read and agreed to the published version of the manuscript.

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Data availability statement

New experimental data have been created and shared via Google Drive. Relevant links are provided in the text of this paper.

Conflicts of interest

The authors declare no conflict of interest.

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Specific features of implementing digital games in mathematics lessons in secondary schools of Ukraine and Israel

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Abstract

The article presents an analysis of the features of the implementation of digital games in mathematics lessons in secondary schools in Ukraine and Israel, using data clustering methods and graphic analysis. The choice of these two countries is determined by the opportunity to compare educational systems operating under different cultural, socio-economic, and infrastructural conditions, as well as their shared experience of adapting to crisis situations, including state of emergency (including martial law in Ukraine), which has stimulated the search for innovative teaching approaches. The results of the analysis of students' attitudes regarding the possibility of using digital mathematical games in the educational process and their interest in mathematical digital games are characterized. As a result of the study, the growth of interest of Ukrainian students in digital mathematical games was noted. In general, there is a trend towards the introduction of digital games at various levels of education, but there are a number of unresolved important issues, including didactic ones. The study is based on a mixed-methods approach combining quantitative surveys and qualitative analysis using data clustering techniques (DBSCAN, K-means) and graphical interpretation of the results. Using a mixed-methods approach, including quantitative surveys and qualitative analysis (K-means clustering, DBSCAN for cluster estimation, Davies-Bouldin Index, and graphic analysis using Python for visualizations), the research aimed to determine and analyze the features of digital game implementation in mathematics lessons. A comparative analysis of students in Ukraine and Israel revealed a high level of interest in using the digital math games (over 80% of respondents) alongside a low level of actual implementation by teachers. Key findings indicate that while both Ukrainian and Israeli students expressed strong interest in using the digital math games in class (over 80% in both countries), there is a notable gap between this desire and actual teacher implementation. Although there was no direct interaction between respondents from the two countries, the comparative design allowed the identification of common trends and country-specific challenges. The paper proposes stages for integrating digital didactic games into the educational process and identifies key factors influencing their effectiveness and accessibility. The article outlines the stages of integrating digital didactic games into the educational process, from planning and goal setting to testing, evaluation, and implementation. It emphasizes the importance of considering technical features, design requirements, and user feedback throughout the process to ensure the effectiveness and accessibility of these games. The findings highlight that continuous monitoring and collaboration with teachers, students, and administrators are crucial for assessing the success of digital didactic games and guiding their future use in education.

Keywords

digital games, mathematics education, secondary schools, Ukraine, Israel, cluster analysis, student attitudes, gamification, educational technology

1. Introduction

In today's world, digital education is becoming a key success factor [1, 2]. The integration of digital technologies into all aspects of the educational process is undeniably important [3]. Therefore, one of

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the important strategies of digital transformation for general secondary education institutions is the use of innovative technologies and tools to improve the teaching of mathematics [4, 5].

Digital games are used by many teachers in the process of teaching mathematics to students in secondary school. A study by Palha and Jukić Matić [6] showed that the experience of using Digital game-based learning (DGBL) in the teaching process affects teachers' attitudes towards game-based pedagogy. They found that teachers with different experiences with DGBL had different concerns. For example, teachers with extensive experience with DGBL expressed concerns that students did not focus enough on mathematical concepts when using DGBL, about the relevance of the game to the intended learning outcomes, about the need to adapt the game lesson to individual students, and about how to assess the tasks [6]. In contrast, teachers with little experience were concerned about more technical issues, such as the lack of appropriate games [6]. This study confirms the value of using such games in student learning and provides knowledge about the factors that influence its implementation [6].

Understanding fractions is an essential indicator of later success in mathematics, but it remains a difficult topic for many middle school students. Thoma et al. [7] have proven that digital educational games, which complement traditional learning, effectively promote the understanding of fractions. Seventh-grade students (12.3 years old) from schools in Germany participated in the study [7]. Relationships between performance in Semideus' fraction game and specific aspects of fraction comprehension were explored [7]. The results confirm that game performance is significantly correlated with math achievement and whole number arithmetic skills [7]. In addition, significant connections are observed in the understanding of fractions, for example, comparing the size of a fraction and the order of fractions [7]. However, according to scientists, the question remains open to what extent these games can be effective in understanding fractions (part-whole ratio, fraction size, fractional arithmetic) [7].

The problem of math anxiety is relevant for many generations. If this problem is not addressed in school education, it can have long-term consequences and negatively affect careers and life in the future. The study, which was conducted in Taiwan by Ng et al. [8] showed, that children who are afraid of math have worse grades in general, because math anxiety is a serious problem that inhibits learning. Their research showed that even short-term intensive learning to using the digital math games can have a significant impact on reducing math anxiety and improving students' math skills [8]. This makes them a valuable early intervention tool that can help children overcome this problem and succeed in math [8].

Yang et al. [9] suggest using interactive mobile games with a help-seeking mechanism to improve elementary school students' mathematics learning. Their experiment showed that this approach really helps improve learning outcomes and student motivation [9]. They found that games with a help-seeking mechanism were particularly useful for students with low self-esteem [9]. The study highlights the importance of social interaction and collaboration during mobile learning [9]. This approach can be a valuable tool for increasing students' interest and performance in mathematics.

Chan et al. [10] highlights the potential of digital environments to enhance mathematics education in secondary schools. Gaming computer systems help middle school students better understand mathematical equivalence, an important concept for STEM (Science, Technology, Engineering, and Mathematics) disciplines [10, 11, 12, 13, 14]. The digital environments "From Here to There!" was effective for both high and low prior knowledge students [10, 15]. Research by Intergalactic Education LLC shows that using gamification in STEM education programs can motivate more students, particularly minority groups, to study STEM disciplines [16]. Park [16] explored a software platform that used machine learning to analyze educational analytics using the Space World game simulation platform [16]. The study also revealed shortcomings in existing educational technology solutions, such as the display of high-quality graphics and inefficient use of educational data [16].

Israeli researchers Hayak and Avidov-Ungar [17] consider the possibilities of training teachers to use digital games as part of the learning process, including mathematics in elementary school [17]. Worthy of attention are the intelligence of Israeli researchers in the field of studying the opinion of parents, regarding the use of digital games in teaching students mathematics as an alternative to traditional homework [18].

Academic research suggests that digital education can help high school students acquire the math skills they need to succeed in the 21st century, but there are still many unanswered questions.

The *purpose of the research* is to determine and analyze the features of the implementation of digital games in mathematics lessons in secondary schools of Ukraine and Israel using data clustering methods and graphic analysis.

2. Research methods

The research used both quantitative and qualitative methods for data analysis. First of all, it is a method of system analysis, modeling, methods of machine learning, in particular, cluster analysis, a survey method, and graphic analysis, as well as methods of abstraction, formalization, generalization, comparison, and others.

Let us present some of these methods in more detail.

In order to determine the features of the use of the digital math games in the process of teaching mathematics to secondary school students, a questionnaire was used, the questions and answer options of which are presented below:

№1. Enter your gender. (Male / Female).
№2. In which area do you live? (Urban / Rural).
№3. Enter your age. (Input field).
№4. Specify the class in which you study. (Input field).
№5. How often do you play computer (especially phone) games? (Several times a week / I used to play, but now I don't play / Every day / Several times a month / Several times a year).
№6. Have you ever played computer math games? (Yes, I played such games / I didn't play / Friends or acquaintances played).
№7. Have your math teachers used computer math games in their math lessons? (No / I don't remember / Yes).
№8. Would you like computer math games to be used in maths at school? (No / Yes).

After cleaning the data obtained as a result of the questionnaire, preprocessing methods were applied to conduct cluster analysis. The DBSCAN method was used for preliminary estimation of the number of clusters [19]. The Davies-Bouldin Index was also used to estimate the given number of clusters for the K-means method [20]. As previously mentioned, machine learning using the K-means method was used to determine the centroids of the clusters [20, 21].

Data pre-processing and data clustering were carried out in the Google Colab environment [22] using the Python programming language [23].

A study on the definition and analysis of the features of the implementation of the digital math games was conducted in 2023 among students of grades 5-11 of secondary schools in Vinnytsia and Chernivtsi regions. The survey of students was carried out using an online questionnaire.

The survey of Israeli students, which included 77 respondents of different ages and both genders, was carried out using the same online questionnaire as in Ukraine to ensure the comparability of results.

In the presented work, we rely on the general principles that underlie modern digital education, which include elements of constructivism, emphasizing the active role of the student in learning, as well as ideas of gamification, relating to motivation and engagement through game elements. According to the constructivist approach, learners actively construct knowledge through interaction with content, peers, and the learning environment, rather than passively receiving information. Digital games provide an interactive, feedback-rich context that supports such active engagement, enabling students to test hypotheses, apply concepts, and receive immediate feedback on their performance. According to the constructivist approach, learners actively construct knowledge through interaction with content, peers, and the learning environment, rather than passively receiving information. Digital games provide an interactive, feedback-rich context that supports such active engagement, enabling students to test hypotheses, apply concepts, and receive immediate feedback on their performance. Gamification theory, which involves the use of game design elements in non-game contexts, highlights how mechanics such as points, levels, badges, and challenges can foster motivation and sustained engagement. In mathematics education, these elements can help reduce anxiety, maintain attention, and encourage repeated practice, which is essential for mastering complex concepts. Furthermore, the combination of constructivist learning and gamification principles aligns with self-determination theory by supporting students' needs for autonomy, competence, and relatedness. By grounding the design and implementation of digital math games in these theoretical frameworks, educators can ensure that such tools are not only engaging but also pedagogically sound, aligning gameplay with targeted learning outcomes and cognitive development processes.

The selection of Ukraine and Israel as the focus countries for this study was intentional, as it enables the comparison of two educational systems operating in different cultural, socio-economic, and infrastructural contexts. Both countries have faced crisis situations, including state of emergency (including martial law in Ukraine), which have accelerated the search for flexible and innovative teaching methods such as gamification. This comparative perspective allows for the identification of both shared trends and country-specific challenges in the integration of digital didactic games into mathematics education. Although there was no direct connection or interaction between the respondents from the two countries, the same research design, questionnaire, and data analysis methods were applied in both contexts. This approach ensured the comparability of the results while respecting the distinct educational environments of each country.

3. Results

For a comparative study of the use of digital didactic games in mathematics education, Ukraine and Israel were intentionally selected to examine how cultural, socio-economic, and infrastructural factors of different educational systems influence the outcomes of game-based learning. In addition, both countries have experience of crisis situations under state of emergency (including martial law in Ukraine), which forced them to look for new flexible educational solutions, including in the form of gamification. This provides a basis for comparing their effectiveness in conditions of stress or instability.

A survey was conducted to determine the specifics of the implementation of digital games in mathematics lessons in secondary schools in Ukraine. 190 secondary school students took part in the survey. After cleaning the received data, a dataset consisting of 180 samples of respondents' answers was formed for further analysis.

The textual data were transformed into numerical features to implement k-means machine learning to identify patterns that characterize respondents' attitudes toward the use of digital games in secondary school mathematics classes. This was implemented using the code below:

```
data['N1'].replace(['Male', 'Female'],
              [1, 2],
              inplace=True)

data['N2'].replace(['Urban', 'Rural'],
              [1, 2],
              inplace=True)

data['N5'].replace(['Several times a week', 'I used to play, but now I
              don't play', 'Every day', 'Several times a month',
              'Several times a year')],
              [1, 2, 3, 4, 5],
              inplace=True)

data['N6'].replace(['Yes, I played such games', 'I didn't play',
              'Friends or acquaintances played'],
```

```
                [2, 0, 1],
                inplace=True)

data['N7'].replace(['No', 'I don't remember', 'Yes'],
                [0, 1, 2],
                inplace=True)

data['N8'].replace(['Yes, it would be interesting', 'Yes, can be
                tried', 'No, it's inappropriate in math lessons',
                'Yes, I would replace all lessons with computer
                games'],
                [1, 1, 0, 1],
                inplace=True)
```

At the next stage of the research, a preliminary assessment of the number of clusters that can be identified in the set of data instances was carried out.

The preliminary estimate of the number of clusters using the DBSCAN [19] method is 3 clusters. As a result of the Davies-Bouldin Index evaluation [24], a value of 0.4 was obtained, which is a low value that indicates a relatively good degree of similarity of each cluster.

As a result of the application of the K-means data clustering algorithm, the centroids of the clusters were determined, which are presented in table 1. In the cluster analysis, we will consider age and gender components, as well as questions related to the attitude of respondents to the use of digital games, in particular, mathematical games, and questions related to the experience of using such games in mathematics lessons in secondary school in Ukraine. This is question №1, №3 – №8. The values of the centroids were rounded to a whole number.

Table 1
The centroids of the clusters.

Question number	Cluster 1	Cluster 2	Cluster 3
№1	1	2	1
№3	16	11	13
№4	10	5	8
№5	2	2	2
№6	1	1	2
№7	1	1	1
№8	1	1	1

According to the results of the cluster analysis, three groups were obtained, which have the following characteristics (table 1): the first cluster includes mainly girls aged 16 years old, studying in the 10th grade; the centroids of the second cluster are 11-year-old boys studying in the 5th grade; the third cluster is dominated by 13-year-old respondents, girls studying in the 8th grade.

Within each cluster, the indicator of the level of interest of students in digital mathematical games in the process of learning mathematics was evaluated in accordance with the purpose and objectives of the study (table 1). According to the conducted analysis, we observe that there are no significant differences between boys and girls in the amount of time they spend playing digital games. Respondents' answers regarding how often they play computer games turned out to be identical for all clusters – "I used to play, but now I don't". The reasons for such an answer can be different. It can be assumed that in general, interest in digital games may have decreased due to excessive use of them earlier.

The respondents of the first and second clusters are characterized by the fact that they themselves have not played mathematical digital games, but they know about the existence of such games because their friends or acquaintances have played mathematical games (table 1). On the other hand, the respondents of the third cluster played mathematical computer games and are familiar with them.

Also common to all clusters is that students do not remember teachers using digital games in math lessons (table 1). In our opinion, this indicates insufficient awareness of Ukrainian mathematics teachers with the possibilities of using digital educational games in the process of teaching mathematics. And it also shows their doubts that with the help of digital games it is possible to acquire the necessary knowledge, skills, and abilities in mathematics.

It should be noted that all respondents expressed interest in using the digital math games in math lessons (table 1), regardless of gender, age or class of study. When choosing statements that appeal to respondents, they could choose several answer options. In particular, the largest choice fell on the statements "Yes, it would be interesting" and "Yes, can be tried". Thus, we can affirm the relevance and expediency of using digital games in the process of teaching mathematics students.

Analyzing the respondents' answers to the last two questions, we note that there is a discrepancy between the wishes of students regarding the use of digital games in mathematics lessons and the actual state of implementation of digital games as part of the learning process (table 1).

That is, there remains a discrepancy between the enthusiasm of researchers and policy makers in the field of gamification of education, on the one hand, and practical issues of evaluation, selection and implementation of digital games in the educational process, on the other (table 1). The graphical interpretation of the obtained results is presented in the form of a combination of selected clusters for data analysis.

Butterfly charts were built using the Python programming language to analyze the specifics of the use of digital games in secondary school mathematics classes depending on the residence of the respondents in Ukraine (figure 1).

The numbering of the investigated factors characterizing the respondents' answers, which was done to improve the display of figure 1 are presented in table 2.

Figure 1: Proportions of students based on the category of residence in Ukraine (City / Village, %).

Table 2
The numbering of the investigated factors characterizing the respondents' answers.

Question number	Respondents' answers
№1	Played digital mathematical games
№2	Didn't play digital mathematical games
№3	Teachers used digital mathematical games
№4	Teachers didn't use digital mathematical games
№5	I wish math teachers would use digital mathematical games
№6	I would prefer that math teachers not use digital mathematical games

Table 3 presents data from the survey results, which represent the percentages of respondents living in rural and urban areas, as well as the survey results in quantitative and percentage relation to the total number of respondents living in urban and rural areas, respectively.

Table 3
Results of the survey of respondents in quantitative and percentage terms who live in urban and rural areas in Ukraine, respectively.

Factor	Number of responses City / Village	Percentage of responses City / Village, (%)
City / Village	134 / 52	72 / 28
Women	78 / 25	58 / 48
Men	56 / 27	42 / 52
№1	93 / 34	69 / 65
№2	41 / 18	31/ 35
№3	25 / 7	19/ 13
№4	109 / 45	81 / 87
№5	125 / 44	93 / 85
№6	9 / 8	7 / 15

Based on the results of the survey, an analysis of students' answers was carried out depending on the type of their place of residence. Thus, 72% of the respondents live in the city, 28% live in the countryside. Since there is an uneven distribution of respondents by type of place of residence, it was decided to analyze respondents' answers in percentage terms (figure 1 and table 2).

So, among the respondents interviewed in urban areas, the share of girls was 58%, while that of boys was 42% (figure 1 and table 2). In rural areas, respectively, the share of girls is 48%, while that of boys was 52% (figure 1 and table 2).

There are certain differences between rural and urban students in the answer to the question "How often do you play digital games?". Respondents living in urban areas play digital games more (69% of respondents answered that they play every day or several times a week) than students living in rural areas (respectively, 65% of respondents play daily or several times a week) (figure 1 and table 2).

It should be noted that the vast majority of respondents from both rural and urban areas expressed interest in using the digital math games in math lessons. When choosing statements that appeal to respondents, they could choose several answer options. In particular, the largest choice fell on the statements "Yes, it would be interesting" and "Yes, can be tried". 93% of urban students gave exactly such answers, while among students in rural areas this indicator is somewhat lower (85% of students believe that it would be interesting for them if the digital math games were used in mathematics lessons) (figure 1 and table 2).

Regarding the use of digital didactic games by teachers in mathematics lessons, it can be stated that teachers in urban areas use such games more often (19% of urban students and 13% of students from rural areas) (figure 1 and table 2).

The analysis from the point of view of the gender characteristics of students regarding the use of digital games in mathematics lessons in secondary schools is also worthy of attention. Butterfly charts were built using the Python programming language (figure 2). According to the previously indicated table, the numbering of the researched factors of the table 4 was used.

Table 4 presents the survey results. The percentage of male and female respondents is given. Also, in quantitative and percentage ratio according to the volume of male and female respondents, the results of the survey are presented.

The table shows that 103 girls and 83 boys took part in the survey, which is 45% and 55% of the total number of respondents, respectively. That is, there were 10% more girls (figure 2 and table 4).

Among the respondents, the share of girls living in cities was 76%, while that of boys was 67% (figure 2 and table 4). In rural areas, respectively, the share of girls is 24%, while that of boys was 33% (figure 2 and table 4).

The percentage of girls and boys who play the digital math games is almost the same, with 67% of girls and 70% of boys (figure 2 and table 4). Similarly, the positive answers of respondents who do not play the digital math games were almost evenly distributed – the share of girls is 33%, while that of

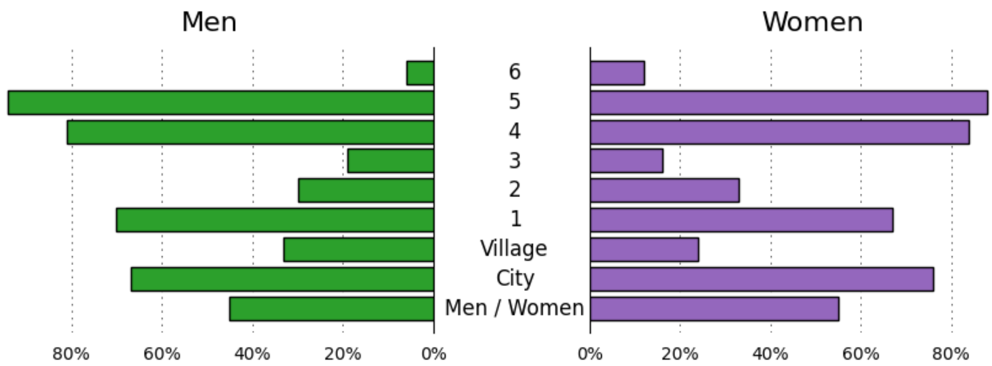

Figure 2: Ratio of students by gender (Male / Female, %), Ukraine.

Table 4
The results of the survey of respondents in quantitative and percentage terms according to gender, Ukraine.

Factor	Number of responses Male / Female	Percentage of responses Male / Female, (%)
Male / Female	83 / 103	45 / 55
City	56 / 78	67 / 76
Village	27 / 25	33 / 24
№1	58 / 69	70 / 67
№2	25 / 34	30 / 33
№3	16 / 16	19 / 16
№4	67 / 87	81 / 84
№5	78 / 103	94 / 88
№6	5 / 12	6 / 12

boys was 30% (figure 2 and table 4). However, there are more students (girls and boys) who play the digital math games.

Respondents' answers regarding whether teachers use digital mathematical games in mathematics lessons were distributed as follows (figure 2 and table 4): they are used – answered by 19% boys and 16% girls; not used – 81% boys and 84% girls . That is, there is a significant preponderance of student responses that teachers do not use the digital math games in math lessons.

It was important to determine whether students wanted their teachers to use mathematical computer games in their mathematics lessons. The vast majority of students answered positively to this question, but 94% boys, compared to 88% girls, expressed a greater desire to use the digital math games in mathematics lessons (figure 2 and table 4). Similarly, fewer boys (6%) gave a negative answer to this question, compared to 12% girls (figure 2 and table 4). That is, more boys showed interest in this type of games than girls.

Let's analyze the results of the survey of respondents in Israel in quantitative and percentage terms according to gender. The survey of Israel schoolchildren was conducted on the same questions as the Ukrainian ones (table 2), in which 77 schoolchildren of different ages participated. Based on the survey data, Butterfly charts were constructed using the Python programming language (figure 3). The numbering of the studied factors in the figure corresponds to the factor number in the table 5.

According to the results obtained (table 4 and table 5), we observe that among Ukrainian schoolchildren there are no significant differences between boys (69%) and girls (65%) in affirmative answers to the question "Have you played digital mathematical games?". In contrast, among Israeli schoolchildren, the number of boys who played the digital math games slightly exceeds the number of girls (63% of boys and 56% of girls).

It is worth noting that among Israeli schoolchildren, the percentage of girls who claim that teachers used digital mathematical games in mathematics lessons is significantly higher (about 20% of boys and

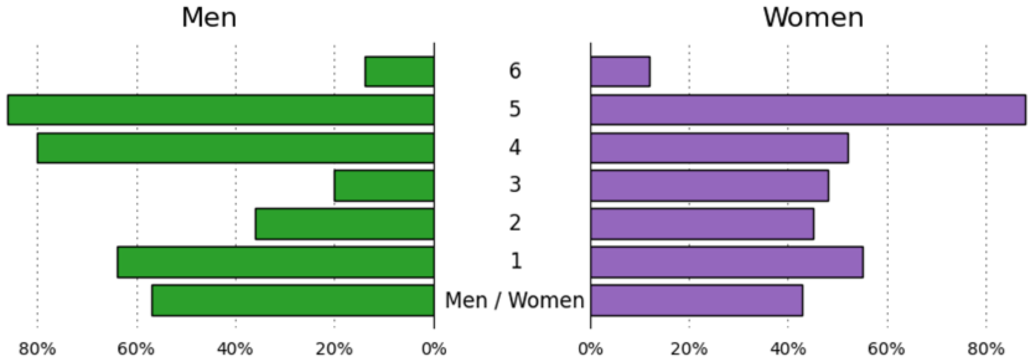

Figure 3: Ratio of students by gender (Male / Female, %), Israel.

Table 5
The results of the survey of respondents in quantitative and percentage terms according to gender, Israel.

Factor	Number of responses Male / Female	Percentage of responses Male / Female, (%)
Male / Female	44 / 33	57 / 43
№1	28 / 18	64 / 55
№2	16 / 15	36 / 45
№3	9 / 6	20 / 48
№4	35 / 17	80 / 52
№5	38 / 29	86 / 88
№6	6 / 4	14 / 12

more than 50% of girls) (table 4). At the same time, among Ukrainian schoolchildren, these data are almost the same by gender, but are significantly lower than among Israeli schoolchildren (less than 20%) (table 5). In our opinion, this indicates that Israeli teachers are more familiar with the possibilities of using digital didactic games in the process of teaching mathematics than Ukrainian teachers and use them in their own activities.

It should be noted that both Israeli and Ukrainian respondents expressed interest in using the digital math games in math lessons. Regardless of gender (more than 80% of both boys and girls in both studies) (table 4 and table 5).

An interesting result is that among Israeli schoolchildren, a slightly larger number of male respondents do not prefer digital games in math lessons (14% of boys and 11% of girls) (table 5). Among Ukrainian schoolchildren, on the contrary, a larger number of girls prefer traditional math lessons, without the use of digital games (7% of boys and 13% of girls) (table 4). And in general, the percentage of Israeli schoolchildren who consider math lessons without digital games to be more appropriate is higher than among Ukrainian schoolchildren.

4. Discussion

The findings of the study confirm several important statements. First, both Ukrainian and Israeli students demonstrated a consistently high interest in the use of digital mathematical games in classroom learning (over 80% in both countries), which indicates the potential of such tools to increase engagement and motivation in mathematics education. Second, despite this interest, the actual use of digital games by mathematics teachers remains relatively low, especially in Ukraine, highlighting a gap between student expectations and current teaching practices. Third, the comparative analysis revealed that Israeli teachers integrate digital didactic games more frequently than their Ukrainian counterparts, possibly due to greater familiarity with such tools and better access to technological resources.

Another important conclusion is that cultural, socio-economic, and infrastructural factors influence the implementation process. Both countries share the experience of adapting their education systems under crisis conditions, which has driven the search for flexible, technology-based teaching solutions. However, differences in teacher training, resource availability, and institutional support shape distinct implementation patterns in each country.

The study also found no direct interaction between respondents from Ukraine and Israel; instead, the research design was based on parallel surveys using identical questionnaires and analysis methods, which allowed for a valid comparison of attitudes and experiences. Based on these results, the authors formulated the stages of integrating digital didactic games into mathematics education, emphasizing planning, technical preparation, testing, evaluation, and continuous improvement. This structured approach, combined with stakeholder feedback, can help bridge the gap between the proven interest of students and the actual application of digital games in mathematics lessons.

We can assume that Israeli schoolchildren's interest in digital games in general may have decreased due to their excessive use earlier, while Ukrainian schoolchildren did not often have the opportunity to play mathematical digital games in class.

As a result of the analysis of the monitoring data of the respondents' responses and our own observations, we determined the stages of implementing digital games in the educational process (figure 4).

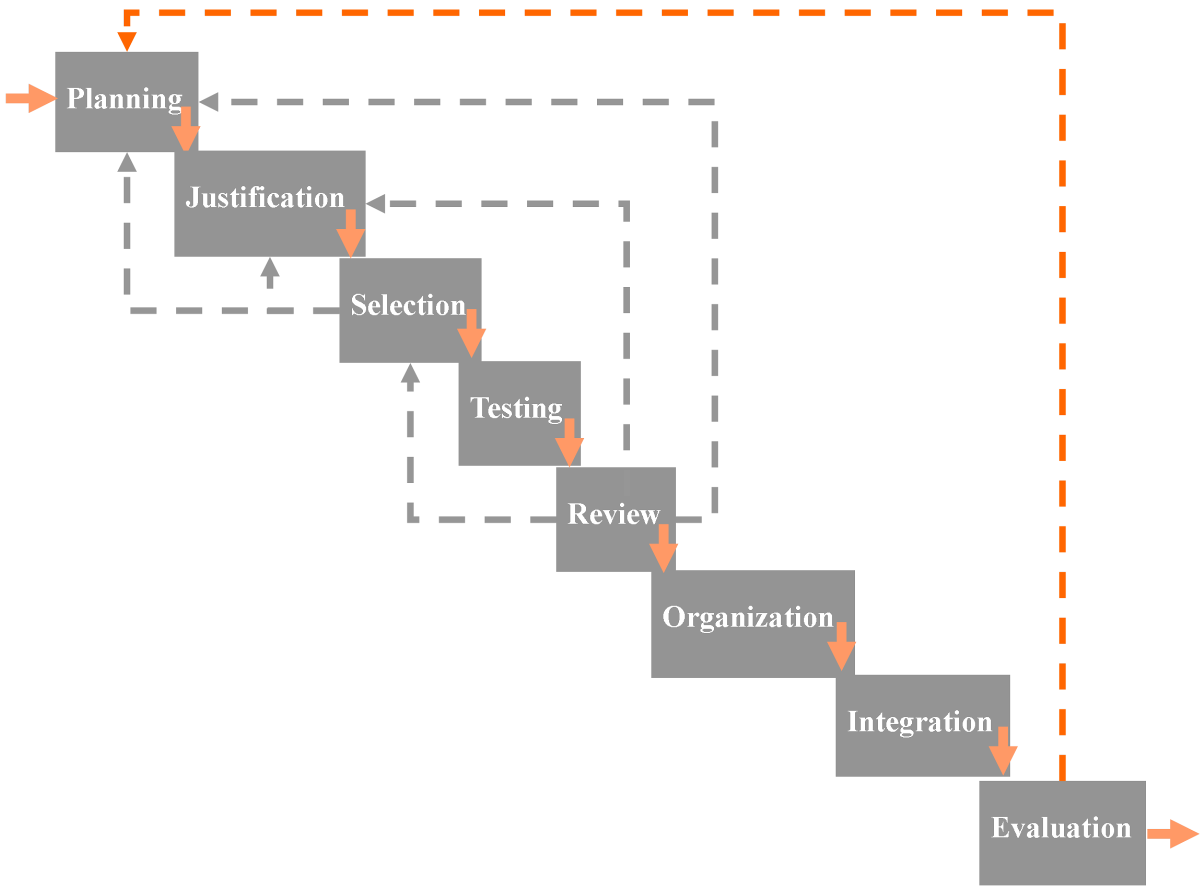

Figure 4: The stages of implementing digital games in the educational process.

At the planning stage, the goals of implementing a digital game are determined. The age of the students is determined. The place of the game as part of the learning process is determined (whether it is an explanation of new material, consolidation of knowledge, reflection, or assessment), the digital platform on which the game is placed or on which the game will be created using the platform's tools for creating such games is determined, and the possibilities of creating a game by a teacher as an independent software product are also considered. The educational goal and learning outcomes are determined. Will the digital didactic game be a separate software product or will it complement an existing game.

At the stage of target justification, specific educational tasks that will be solved in the process of using the game are determined, requirements for the game design in accordance with the age characteristics of the students, the level of their educational achievements. The requirements for the game genre, game interface, and its interactivity are also considered. It is determined whether the game will be team or individual. Language support requirements are taken into account. Important issues of game accessibility are resolved.

At the stage of selection and analysis of the capabilities and technical features of the selected digital didactic game, the game's compliance with the goals and requirements of the previous stages, compatibility with relevant technical and software tools are checked. Game security issues (unwanted content, advertising) are considered. The need for game elements to stimulate students' interest (competitions, achievements, awards) is determined. An important feature of a digital game is its practical orientation, therefore it is also necessary to determine whether there is a need for the game's tasks to be connected with real-life situations.

The testing stage of a digital game is implemented with the participation of a teacher; students, parents, and the administration of a secondary education institution may also be involved in the testing stage of the game.

At the review stage, the results of the digital game testing are summarized, the game's compliance with the requirements is assessed. The need to revise the current requirements for the game is determined, and proposals for possible additions to these requirements are considered.

At the organizational stage, the necessary equipment, software, and access to the game are prepared and configured (Internet, configured devices). Instructions for students on the rules of the game and expected results are also developed. Possibilities of providing support for students during the game, their cooperation if the game is a team game, assistance in solving technical or organizational issues are studied.

At the stage of integration (use) of a digital game into the educational process, the game is directly used and the results of students' academic achievements are monitored, their opinions on the use of the game are monitored. At this stage, it is also important to conduct a survey on the use of this game in the educational process among all stakeholders (teachers, parents and school administration).

Analysis, evaluation and interpretation of the results of the implementation of a digital game, monitoring of students' opinions on the use of the game in the educational process are important for determining the effectiveness of using the game, as well as for further planning of lessons, making a decision on the further use of the corresponding digital game in the educational process. An important aspect of interpreting the results of using a digital game is determining the need for its improvement or replacement with another game, as well as making a decision on whether to continue using the selected game and disseminating effective best practices for its use in the educational process.

5. Conclusion

In summary, it is observed that the results of this study align with broader global trends in education, which increasingly emphasize the integration of digital technologies and game-based learning to enhance student engagement, personalize instruction, and develop 21st-century skills. The high level of interest among students in both Ukraine and Israel mirrors international research showing that interactive, technology-enhanced learning experiences can increase motivation and improve conceptual understanding in mathematics. At the same time, the observed gap between student enthusiasm and teacher implementation reflects a common challenge across many education systems —- the need for targeted professional development, adequate resources, and institutional support for innovative teaching methods.

Currently, in Ukraine, the introduction of digital games into the process of teaching mathematics raises many controversial issues related to various aspects, in particular, the determination of the goals, place and limits of the use of digital games in the educational process, the readiness of mathematics teachers for methodically balanced use of digital games in the process training, to conscious selection of software products. After all, a significant number of teachers are not familiar with the concept of learning based on video games. Even those teachers who use computer games in the process of work face significant difficulties.

There is also an urgent need to develop clear, predictable learning outcomes using digital games that meet national curriculum standards.

That is, there remains a discrepancy between the enthusiasm of researchers and policymakers in the field of gamification of education, on the one hand, and practical issues of evaluation, selection and implementation of digital games in the educational process, on the other.

Based on the analysis of monitoring data and observations in Ukraine and Israel, the stages of integrating digital didactic games into the educational process were identified. These stages include planning the goals and age relevance, justifying the objectives and design requirements, selecting and analyzing technical features, testing the game, reviewing results, preparing necessary resources, and integrating the game into the learning process. Continuous evaluation and feedback from students, teachers, and other stakeholders are essential to determine the effectiveness of the game and decide on its improvement or continued use in the educational system.

The results of the study demonstrate that, despite the high interest of students in the digital math games, there is a significant gap between students' desire to use the digital math games and teachers' actual use of such games, which reflects the broader problem of adapting educational practices to modern digital realities. In future studies, we plan to focus on developing effective methods for introducing digital games into the educational process, investigating the impact of specific types of games on different aspects of mathematics learning, as well as studying factors that hinder or facilitate their wider use by teachers. Additionally, further investigation into teacher training models, school-level implementation strategies, and policy frameworks could provide actionable recommendations for bridging the gap between educational innovation and everyday classroom practice. Collaborative cross-country studies, similar to the present work, would also help identify universal best practices and context-specific adaptations necessary for successful integration of digital didactic games worldwide.

Thus, we consider it appropriate to conduct research related to the study of the place and role of the mathematics teacher in the organization of the educational process with the use of digital games, the interests of mathematics teachers in Ukraine and Israel who plan to use mathematical computer games in order to improve the effectiveness and quality of mathematics education. In addition, this issue remains understudied in Ukraine.

Declaration on Generative AI

The authors have not employed any generative AI tools.

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Development of a PyGame workshop for extracurricular Computer Science education

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Abstract

With the rapid growth of the gaming industry, teaching game development in extracurricular education has become increasingly relevant. The analysis of the recommended extracurricular programs revealed that most of them do not completely cover contemporary game design approaches, suggest the use of outdated or expensive software, and advocate russian resources and services. This study presents a PyGame workshop for extracurricular Computer Science education. The workshop was designed as a step-by-step game creation guide, with each step logically connected to the previous and next lessons, ensuring gradual progress. The Python programming language and PyGame library were chosen for the workshop implementation due to their accessibility, extensive documentation, and suitability for beginners. The workshop was implemented as a website using Google Sites, providing easy access to learning materials, code examples, and resources. The collected feedback indicated high levels of engagement and satisfaction with the learning experience.

Keywords

PyGame workshop, extracurricular education, Computer Science education, game development, Python programming, project-based learning

1. Introduction

In a context where programming is becoming an important tool for solving a wide range of problems, education must provide access to effective and modern teaching methods. In this regard, creating computer games is an ideal combination of technical and creative components that contribute to the comprehensive development of students [1, 2, 3, 4, 5].

Extracurricular education is a flexible tool that allows students to realize their potential through practical activities. In this research, we are trying to examine the interests of students who take part in extracurricular Computer Science events and to test whether they fit what the officially recommended extracurricular programs propose them to study.

As a result of this comparison, we are going to design an extracurricular course that could fill the gap between students' expectations and extracurricular programs' recommendations.

2. Analysis of the current state of extracurricular Computer Science education

2.1. The system of extracurricular Computer Science education in Ukraine

The system of extracurricular Computer Science education in Ukraine is an important component of the educational process that contributes to the development of the scientific and technical skills of young people and their interest in information technologies. It is based on Ukraine's law "On Extracurricular Education" that regulates extracurricular education, as well as methodological recommendations that ensure its quality [6].

The key points of the Ukraine's law "On Extracurricular Education" [6]:

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- The structure of extracurricular education includes state, municipal, and private extracurricular education institutions; other educational institutions as centers of extracurricular education; clubs and associations at the place of residence, regardless of subordination, types, and forms of ownership; cultural, educational, health, sports and other educational institutions and establishments; foundations, associations whose activities are related to the functioning of extracurricular education; relevant government bodies and scientific and methodological institutions; other subjects of educational activity providing educational services in the system of extracurricular education.
- Extracurricular education is carried out in a differentiated manner according to the individual capabilities, interests, inclinations, and abilities of students, considering their age, psychophysical features, and state of health in various organizational forms.
- The main tasks of extracurricular education include educating a citizen of Ukraine, promoting the free development of personality, forming socio-civic experience and patriotism, and a respectful attitude towards family, older generations, and cultural traditions.

The Institute of Education Content Modernisation offers recommendations for the development of STEM education, particularly Computer Science, in secondary and extracurricular educational institutions. Special attention is paid to the use of interactive teaching methods, such as organizing competitions, hackathons, and practical classes in robotics and programming, which contribute to the practical skills development and stimulate interest in modern technologies [7].

2.2. Analysis of student's demands from extracurricular Computer Science education

By its nature, extracurricular education is something that students choose to study voluntarily, that is to say, their interests should be appreciated during the extracurricular programs design. It will ensure their motivation and engagement.

The Computer Science extracurricular education demand can be assessed through the students' participation in scientific projects contests [8].

The analysis of the statistics from the Junior Academy of Sciences of Ukraine contests in the Dnipropetrovsk Oblast for 2014–2024 demonstrates the diversity of areas that attract students. The most popular Computer Science section throughout the studied period is "Multimedia systems, educational and game programs" (since 2023 "Educational, game programs and virtual reality"). This section consistently demonstrates a high level of student involvement, with over 10 participants every year (figure 1). For comparison, in other areas, the number of participants usually did not exceed 10 people (figure 2).

2.3. Review of existing extracurricular education programs related to game development

Despite the high demand from students, the analysis of educational programs recommended by the Ministry of Education and Science of Ukraine showed the absence of specialized courses on game development for extracurricular education (table 1). Some programs partially touch on this topic, such as "Fundamentals of Computer Graphics" by Yu. S. Dorofeyeva, Zh. V. Deineko or "Multimedia Systems, Educational, Game Programs" by V. V. Yefymenko, but their content requires significant changes.

Analysis of existing courses revealed several key problems that may affect the effectiveness of learning. Firstly, some programs have inconsistencies between the programming language, compiler, and sources, which complicates the learning process. In addition, some recommended resources are already outdated and may no longer be supported or relevant to current conditions. Some programs contain paid resources with high costs per user, which can become a barrier for students. Another problem is the presence of russian services and literature, which is unacceptable in the current educational situation, as each program contains such sources.

Given the identified problems, the development of a PyGame workshop for extracurricular Computer Science education appears to be relevant. This will help avoid the mentioned shortcomings, providing

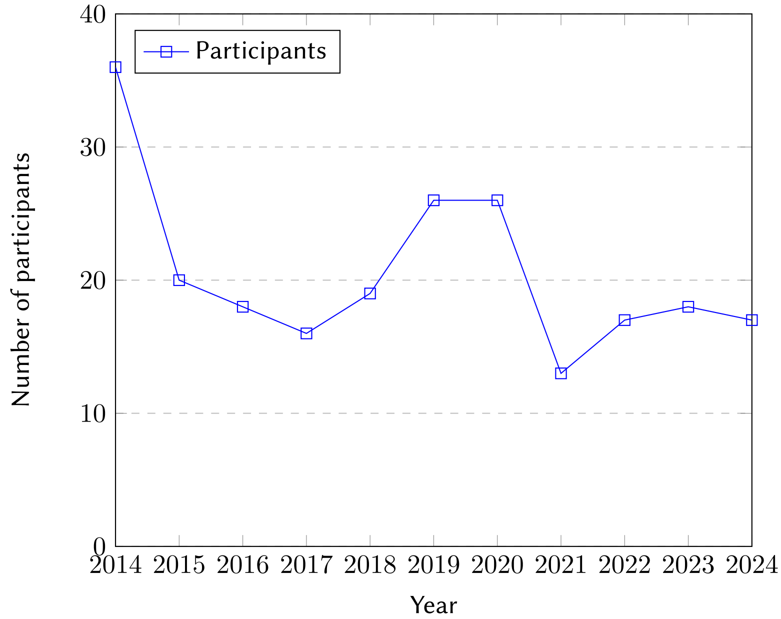

Figure 1: Diagram of the number of participants by year in the field of “Multimedia systems, educational and game programs” (since 2023 – “Educational, game programs and virtual reality”).

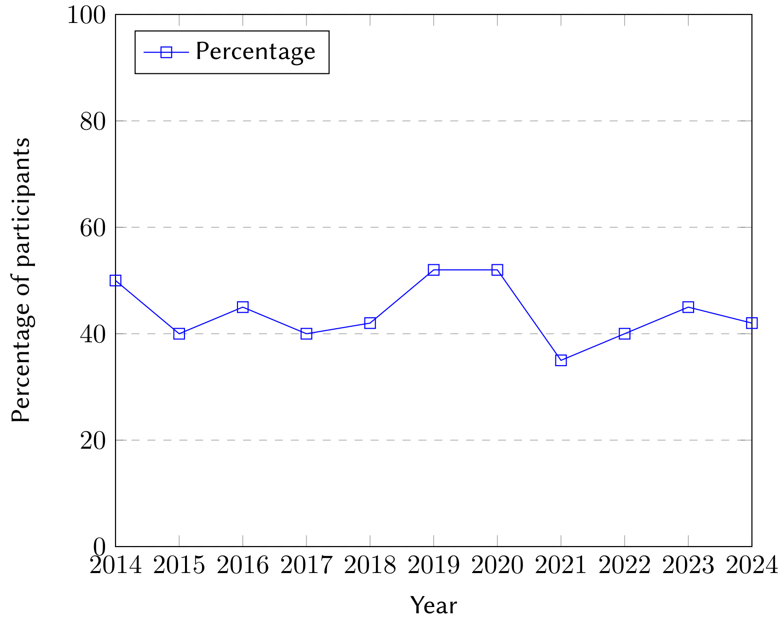

Figure 2: Diagram of the share of participants by year in the field of “Multimedia systems, educational and game programs” (since 2023 – “Educational, game programs and virtual reality”).

students with modern tools for learning programming and creating games that will meet today’s security and relevance requirements.

2.4. Comparison of existing Ukrainian educational courses using PyGame

To develop a PyGame course that meets modern educational needs, it is essential to analyze existing learning programs. This helps identify effective teaching methods, evaluate their strengths and weaknesses, and integrate the best practices into a new curriculum. The following overview examines three Ukrainian educational courses that include PyGame.

Formula [10] offers a PyGame course within its “Graphic Programming” section, following an

Table 1
Review of extracurricular education programs from the collection of educational programs for extracurricular education [9].

Author	Program name	Game Dev related sections	Tools (✓ – relevant, ✗– outdated)	Other remarks
Yu. S. Dorofeyeva, Zh. V. Deineko	Fundamentals of computer graphics	Development of 2D and 3D graphics	✓MS Paint ✓Adobe Illustrator ✓Adobe Photoshop ✗Adobe Flash ✓3D MAX	Presence of Russian-language literature
D. S. Hrebeniuk	Fundamentals of Modern Programming	Description of basic algorithmic structures	✓Microsoft Visual Studio	Inconsistency of programming language, compiler and sources. Presence of Russian-language literature
I. V. Bychkova	Modern Programming Technologies	Basic algorithmic structures, two-dimensional graphics	✓Microsoft Visual Studio ✗Borland C++ Builder	Presence of Russian-language literature
V. V. Yefymenko	Multimedia systems, educational, game programs. Internet technologies and web design	Flash animation	✓Adobe Photoshop ✗Flash	Recommendation of the uCoz tool from a Russian manufacturer. Presence of Russian-language literature

introduction to Python. The course is free and designed STEM education. However, it lacks a clear focus on game development, making PyGame concepts harder to grasp. Additionally, the course structure and navigation are not user-friendly, which may hinder the learning experience.

DystOsvita [11], a Moodle-based distance learning platform, provides a structured PyGame course divided into five modules: a basic game project, event handling, Arkanoid, Mario, and Snake. It is free and suitable for independent learning, with well-organized theoretical explanations preceding practical tasks. However, the course lacks visual examples and has poor text formatting, making content harder to consume. Despite this, its step-by-step approach ensures gradual skill development.

IT Hub [12] offers a comprehensive PyGame course covering Python fundamentals, game development techniques, and project-based learning. It includes teamwork, a demo game, and a final presentation. However, the course is paid, costing 2,400 UAH per month for three months, which limits its accessibility. Without purchasing access, a further detailed evaluation of its content and methodology is difficult.

This analysis highlights key advantages and limitations in existing courses, providing insights for designing an improved PyGame curriculum that combines effective teaching methods while avoiding current shortcomings.

3. Development and approbation of the PyGame workshop

3.1. Choosing the software

For the workshop implementation, the Python programming language and the PyGame library were chosen, which is justified by the following factors:

- Python is one of the most popular programming languages in the world in various areas of development.
- Python is actively used in schools to teach the basics of algorithms and programming, which simplifies the process of integrating a new course into the curriculum.
- Python's easy syntax allows one to quickly master the basics of programming, which is especially important for students who are just starting to learn software development.

- PyGame is a set of Python modules designed for writing games, allowing the creation of fully functional games and multimedia programs.
- PyGame is highly portable and runs on almost every platform and operating system.
- PyGame has a simple core structure, and additional functions are managed by separate modules, which ensures code organization.
- PyGame uses the advantages of modern computer architectures by using multiple CPU cores for faster graphics rendering.

For the development of the course, the Google Sites platform was chosen as a convenient tool for creating a free website with a modern design and necessary functionality.

3.2. Designing the structure and content of the PyGame workshop

The workshop [13] was designed as a step-by-step course for creating the first game in PyGame, where each step is logically connected with the previous and next ones, ensuring a gradual progress. Unlike the discussed extracurricular programs, we decided to implement a project-based learning technique. The central idea was to make students build a functional yet simple game project, which could be used as a core for their further 2D games. We believe that it should increase their motivation and give an idea of how different game design techniques work together. Unlike the school Computer Science course, we could afford more flexible approach in extracurricular education. We expect that our students already know the fundamentals of Python programming.

The workshop begins with a "Main" page, which serves as an introductory one. It presents general information about the course, including the target audience and expected learning outcomes.

The next important part is the "Course" page, where users can familiarize themselves with the PyGame library in more detail. This page presents popular games developed using PyGame, demonstrating the library's capabilities and motivating students to learn. From this page, users can proceed either to the first step or directly to the second if they already have a configured development environment.

The first step of the workshop is devoted to setting up the development environment. It describes in detail the process of installing or updating Python and the PyGame library.

The second step focuses on creating the game world. At this stage, users learn the basic structure of project files and write the initial game code.

In the third step, characters are added to the game. Users learn to create a player and three different types of enemies: fire, ice, and poison.

The fourth step is devoted to creating game objects. At this stage, various elements are added to the game: lava blocks, first-aid kits, and ammunition.

The fifth step is the most complex and covers the implementation of game mechanics. At this stage, users learn to create movement animation, program interaction with objects, implement a shooting system, and manage the health of characters.

The sixth step is the final stage of game creation. Here, users add win and loss menus, improve the game world, and add final touches to the project.

In addition to the main content, the workshop contains a "Resources" page, where all the materials used in the course are arranged: images, videos, and full game code on GitHub [14].

3.3. Approbation of the course

To verify the feasibility, relevance, and effectiveness of the developed course, access to its materials was provided to first-year students of group I-24 who study Python within the "Introduction to Programming" course.

After completing the workshop, the participants completed a feedback survey, which helped gather information about their impressions, the complexity of the materials, the level of interest, and satisfaction with the final results. The survey consisted of two parts: quantitative and qualitative indicators for evaluating the course.

The quantitative assessment on a five-point scale (where 1 is the lowest indicator, 5 is the highest) included the following:

- Compliance of the course with expectations (average score 4.6).
- Difficulty of the educational material (average score 2.6).
- Quality of demonstration examples (average score 4.7).
- Level of interest in the process of creating one's own game (average score 4.7).
- Satisfaction with the result (created game) (average score 4.5).
- Level of interest in working with Pygame (average score 4).
- Desire to continue studying game development in Pygame (average score 4.4).

The qualitative assessment through open questions included the following:

- The most positive aspects of the course.
- Elements of the course that need improvement.
- The most useful components of the course.
- Components that can be optimized or excluded.
- General impressions and suggestions for improvement.

According to the results of the survey, most of the students positively evaluated the course. High scores were given to the quality of demonstration examples, the interest in creating their own game, and satisfaction in working with the Pygame library. Participants noted that the course met their expectations and became a useful and interesting experience for them.

Although some constructive suggestions were received for improving certain aspects of the course, the overall results of the approbation demonstrate the high effectiveness of the workshop. Students noted the practical value of the course, especially in the context of creating their own game projects, which indicates the achievement of the main educational goals.

The conducted approbation confirmed the feasibility of introducing the developed course into the educational process and its compliance with the modern educational needs of students in the field of game development using PyGame.

4. Conclusions

The analysis of educational programs from the Ministry of Education and Science of Ukraine reveals a lack of specialized game development courses for extracurricular education, despite high student interest. Existing programs require significant revisions and suffer from issues like inconsistencies in programming resources, outdated materials, high costs, and the inclusion of russian literature, which is inappropriate in the current context.

We found that Python and the PyGame library are the optimal solution for learning game development. Ease of use, a large number of educational materials, support for different platforms, and wide functionality make PyGame accessible for beginners and convenient for the implementation of game projects.

The development of the workshop structure was based on the principle of step-by-step learning, where each step is logically connected with the previous one. The structure of the course takes into account the interests of students, providing a practical orientation and accessibility of materials such as code, images, and instructions.

Approbation of the course confirmed its relevance and effectiveness. Students positively assessed the accessibility of the material, the quality of demonstration examples, and the opportunity to create their own game. The course met the expectations of most participants, interested them in further studying game development, and became a useful practical experience.

The practical significance of the work lies in the fact that the course can be integrated into coding clubs, groups, or individual training, helping schoolchildren develop logical thinking, creativity, and basic knowledge of game development.

The results of the work demonstrate that the development of such courses is an important step for improving the system of extracurricular education, its adaptation to the interests of students, and trends in the development of information technologies.

Declaration on Generative AI

During the preparation of this work, the authors used Claude 3.7 Sonnet to enhance content and improve writing style. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the publication's content.

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Interactive platform Wordwall within the New Ukrainian School's chemistry lessons

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Abstract

Modern educational trends require the integration of digital technologies into the learning process to enhance its effectiveness and meet the needs of the new generation of students. Interactive platforms, such as Wordwall offer broad opportunities to diversify teaching methods, especially in natural sciences. To increase students' interest in learning chemistry, a series of interactive exercises covering key topics in the 8th-grade chemistry curriculum of the New Ukrainian School has been developed, including the quantitative laws of chemistry, atomic structure, chemical bonding, the specifics of locating the elements in the periodic table, and the properties of environmental gases. The advantages of applying the Wordwall platform into the educational process have been identified: universality, adaptability to individual student needs, interactivity, and accessibility. The developed exercises were verified by 8th-grade students in pilot schools across Ukraine. The study demonstrated that Wordwall is an effective tool for modernizing the learning process in chemistry. Its application makes lessons more engaging and effective; boosts learning quality and develops students' key skills. The use of Wordwall boosts the development of students' digital skills, such as information retrieval, data analysis, and online collaboration. It ensures equal access to educational materials regardless of students' location. Tasks can be completed both in the classroom and at home, which is particularly important in the context of quarantine restrictions or remote study. The concept of the New Ukrainian School emphasizes the competency-based approach, the integration of digital technologies, and an individualized approach to each student. The paper demonstrates that Wordwall meets these requirements, enabling the implementation of NUS' key objectives in chemistry education.

Keywords

Wordwall, Interactive platforms, Digital skills, New Ukrainian School, Chemistry

1. Introduction

1.1. The problem statement

Natural sciences, particularly chemistry, have significant potential for developing the related competencies [1, 2]. They help students build systemic thinking, a scientific worldview, and the ability to solve practical problems [3]. However, traditional teaching methods often fail to meet the needs of modern students, leading to decreased motivation and academic performance. Interactive technologies, which enhance students' cognitive engagement and improve the learning process, are gaining more and more popularity.

Currently, one of the most popular, convenient, and effective interactive learning platforms is Wordwall. This online platform allows setting up various educational tasks that can be easily adapted

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to any subject. Wordwall offers tools for creating quizzes, crosswords, interactive games, and other assignments and these make learning exciting and engaging for students of all ages.

Applying Wordwall into the chemistry lessons in the New Ukrainian School aligns with modern educational trends, like personalized learning, the development of key competencies, and fostering a stable motivation for learning. Due to its flexibility and accessibility, Wordwall allows teachers to effectively organize both in-person and remote lessons, creating an interactive environment for knowledge acquisition and revision.

1.2. Research objective

The objective of the research is to verify the efficiency of the interactive Wordwall platform and to develop tasks for modernizing the educational process within the New Ukrainian School (NUS) chemistry classes.

2. Literature review

It's a common knowledge that chemistry, as a science, requires both theoretical understanding and practical application. Traditionally, chemical education has combined theoretical explanations, laboratory experiments, and knowledge assessment. However, within the NUS framework, priority is given to an activity-based approach, where students actively participate in creating educational content, work in teams, and apply acquired knowledge to real-life situations.

The contemporary education system is increasingly connecting its members with the virtual space and its elements. As a result, the role of games and game tech in education is growing and step-by-step they're becoming the key elements of the learning process [4]. Interactive tasks such as crosswords, quizzes, and simulation games effectively motivate students to study. They not only diversify the educational process but also ensure personalized learning, aligning with one of the core NUS principles – "learning for life".

While digitalization offers new opportunities [5, 6], its implementation comes with quite a few challenges. One of the issues is lack of teachers' readiness to use digital tools. Often, teachers fell that they don't have enough technical knowledge and time to apply digital instruments.

Another challenge is the technical infrastructure. Not all the schools in Ukraine have adequate digital resources. Besides, the access to the Internet and devices is not equal for all students, which creates disparities in learning opportunities.

Nevertheless, gamification and interactive platforms enhance accessibility and engagement in education [4, 7, 8, 9, 10, 11, 12]. Students are more eager to participate when presented with interactive quizzes or puzzles instead of traditional textbooks [13] that can be developed in Wordwall. This resource does not require additional software installation and can be applied in classrooms, remotely, or within a blended education approach. Through tests, puzzles, or speed-based games the assignments developed in Worldwall can be adapted with different chemistry topics, such as atomic structure or chemical reactions, Wordwall boosts the development of the activity-based approach, since the students can not only perceive the theoretical knowledge, but also apply this knowledge with the practical tasks.

Interactive assignments improve both specific subject knowledge and key competencies:

- Digital literacy (students learn to work with digital tools);
- Critical thinking (complex tasks promote data analysis, reasoning and expressing conclusions);
- Communication skills (group tasks enhance collaboration and idea-sharing).

Chemistry is often perceived as a difficult subject due to abstract processes. Interactive platforms help teachers create understandable tasks that visualize these processes such as animations and diagrams [14]. This makes the understanding of some topics, like chemical structure, chemical equations, or the periodic table much easier. Wordwall cam also offer a variety of advantages [15]:

- Allows task customization based on individual students' abilities, offering both advanced exercises for stronger students and simplified tasks for those students, who are struggling with education.
- Enables instant knowledge assessment through automated feedback, which saves time, spent on task control and gives the opportunity to react on the spot if knowledge gaps are found.
- Suitable for in-person, remote, or blended approach, making it a versatile tool.

Wordwall is an accessible platform that does not require complex technical equipment or software [16, 17]. It operates online, allowing its utilization both in schools with basic computerization and at home on any device – computer, tablet, or smartphone.

This platform has an intuitive interface that allows teachers create interactive tasks quickly. This is particularly important for educators implementing modern technologies in the learning process but who may lack experience with more complex digital tools. The platform's simplicity also ensures its effective usage for students of various age groups. One of Wordwall's key advantages is the vast number of ready-made templates for creating interactive exercises, making it adaptable to any chemistry-related topic. As a result, Wordwall can be used both for assessing students' knowledge and for reinforcing material in an engaging, game-based format [18, 19, 20]. The platform supports editing and reusing created tasks. That allows teachers to customize content according to students' knowledge levels, topic specifics, or lesson objectives. Wordwall's flexibility makes it a versatile tool suitable for both classroom work and home study. Interactive exercises developed on the Wordwall platform contribute to increasing students' motivation. Thanks to gamification elements, students become actively engaged in the learning process, and instant feedback helps them self-assess their progress. This is particularly important for studying chemistry, the subject that students often treat as a challenging one [15].

3. Results and discussion

The Wordwall platform provides a wide variety of tools for developing interactive assignments adaptable to different chemistry topics. Using the platform's tools, an interactive application was developed to apply with the "Chemistry. 8th Grade" textbook (authors: L. Midak, O. Kuzyshyn, Ju. Pahomov, and Kh. Buzhdyhan).

The developed interactive assignments follow this template:

- Lesson topic.
- Wordwall exercise template (with a link to the exercise).
- Objective of the exercise.
- Exercise content.
- Expected outcomes.

Let us take a closer look at the functionality of this platform, the templates available for creating different types of tasks, and their potential applications in chemistry. Using the "Quiz" or "Game Quiz" templates, teachers can create test-based assignments or open-ended questions to assess students' knowledge. Additionally, there's a possibility to develop tasks for matching, categorization, or sorting with the relevant templates. An interesting variation of these templates is "Air Balloons". The platform can be applied to crate standard crosswords, fill words, and anagrams to enhance the understanding of chemical terminology.

For studying chemical concepts or analyzing texts, the "Fill in the Blanks" template can be used, or teachers can set tasks requiring students to arrange words in a sentence, events in a sequence, or even compounds in a chemical equation. Interesting randomizing templates include "Wheel of Fortune", "Open the Box", and "Random Cards". They can be used to review a topic or activate the existing knowledge at the beginning of a lesson.

The platform also offers innovative ways to present traditional tasks. For example, chose-the-correct-answer questions can be transformed from a standard test format into interactive challenges such as a maze with obstacles, a flying fruit game, or a plane navigation task where students have to choose the correct answer. Labeling diagrams can be effectively used for studying laboratory equipment, filling tables with relevant data, or exploring the structure of the periodic table. For self-assessment, students can use flashcards or double-sided tiles. To distinguish between myths and facts or classify elements into specific categories, they can use the "True or False" or "Whack-a-Mole" templates. Finally, the pair matching game template not only reinforces chemistry knowledge but also helps improve general memory and concentration skills.

Figures 1, 2, 3, 4, 5, 6, 7, and 8 illustrates the appearance of exercises when edited by the teacher as well as when performed by students.

Task 1

Lesson topic: Binary compounds.

Exercise template: "Whack-a-Mole". https://wordwall.net/uk/resource/81574893

Exercise goal: to quickly distinguish chemical elements, the ions of which have a constant charge.

Exercise content: Students hit moles near a sign with the symbol of a chemical element, the ion of which has a constant charge (figure 1).

Expected outcomes: Students will learn to correctly and quickly identify chemical elements the atoms of which form ions with a stable charge.

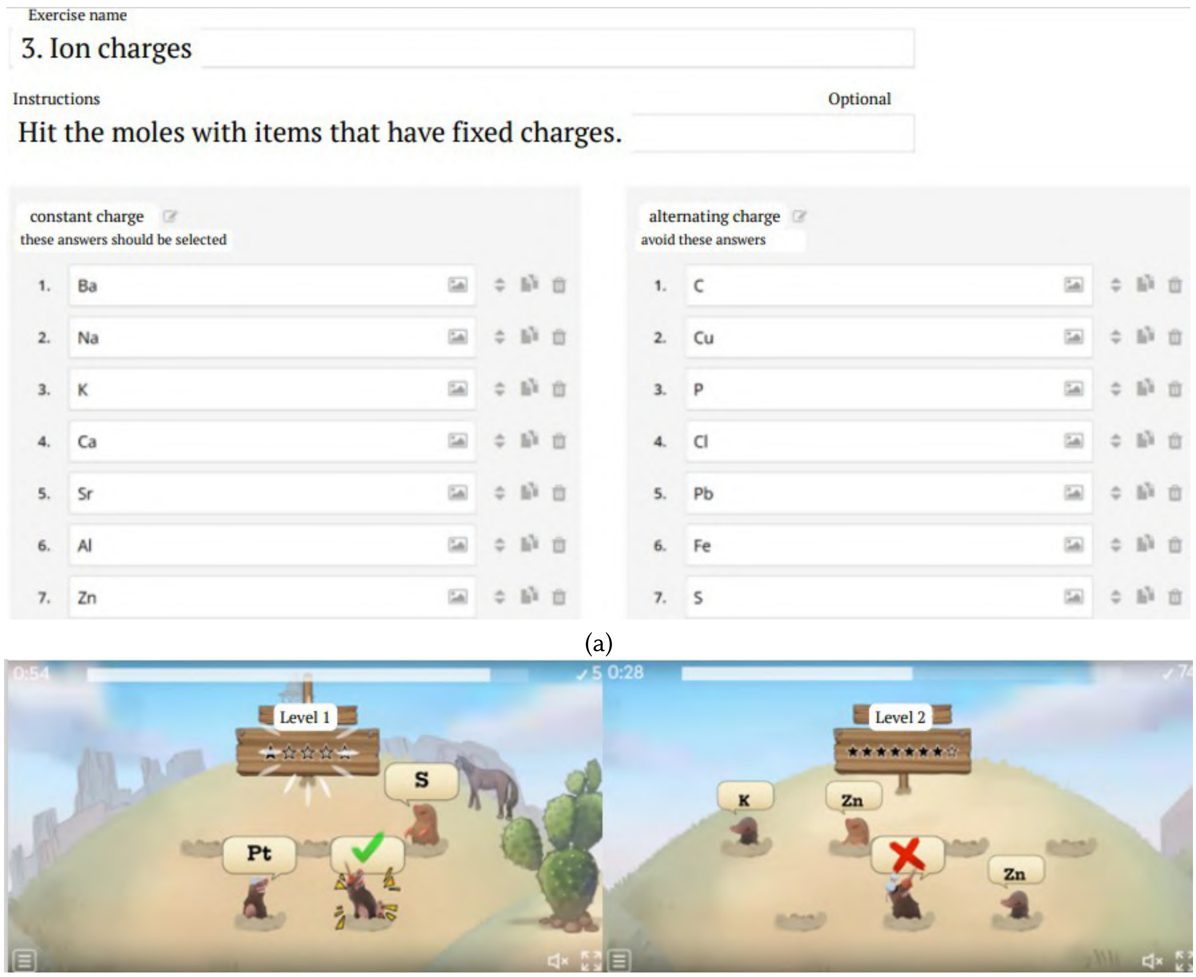

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Figure 1: Interactive exercise "Ion charges": (a) exercise editing; (b) exercise completion.

Task 2

Lesson topic: Principles of writing formulas and names of binary compounds.

Exercise template: "Maze Chase" https://wordwall.net/uk/resource/81574557.

Exercise goal: To learn how to write chemical formulas for binary compounds based on their names.

Exercise content: Students navigate a maze, selecting the correct chemical formula corresponding to the given name of the compound (figure 2).

Expected outcomes: Students will learn to build chemical formulas of binary compounds and improve their concentration skills.

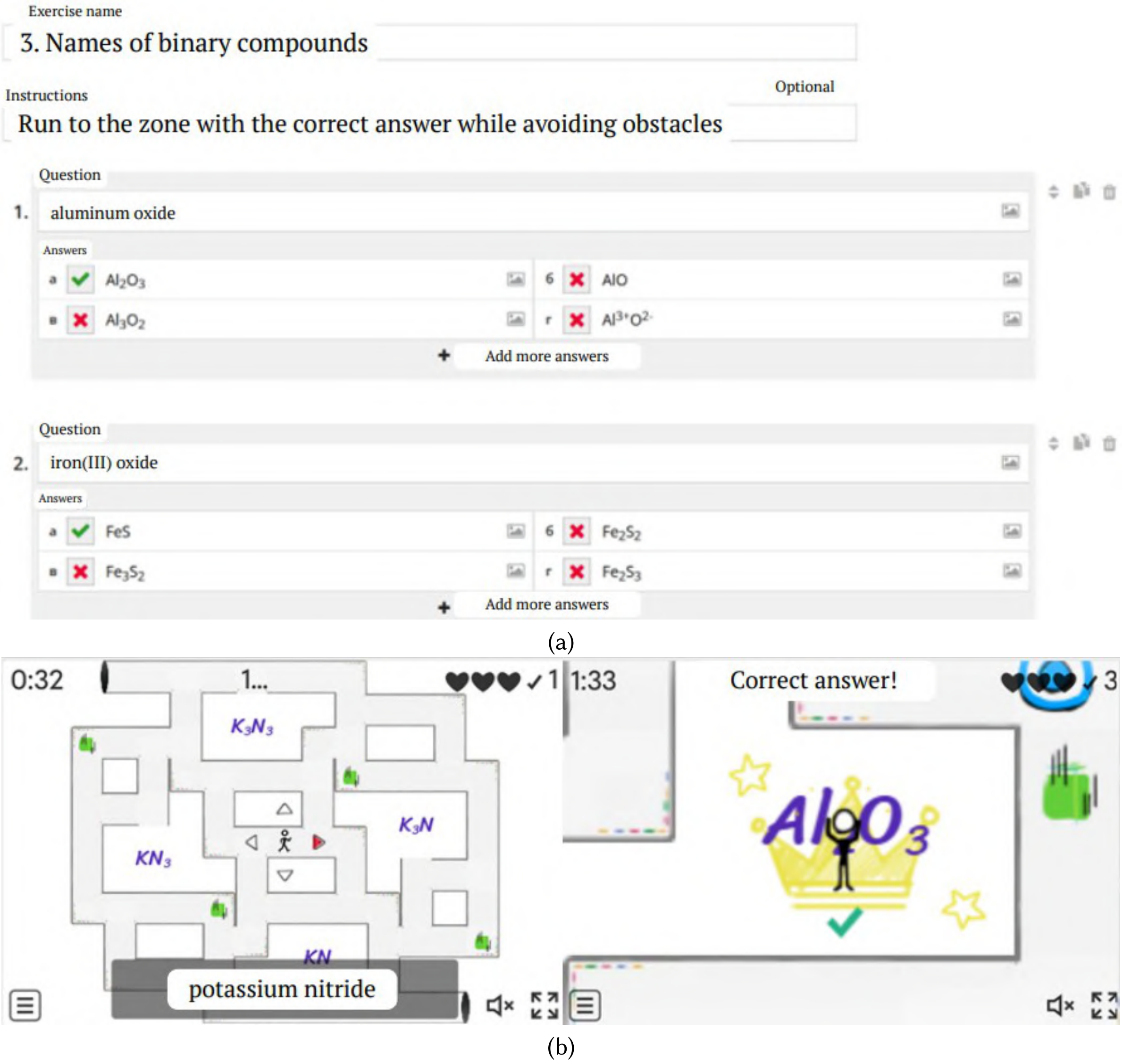


Figure 2: Interactive exercise "Names of binary compounds": (a) exercise editing; (b) exercise completion.

Task 3

Lesson topic: Relative atomic mass.

Exercise template: "Matching Pairs" https://wordwall.net/uk/resource/81575119.

Exercise goal: To learn the relative atomic masses of the most common chemical elements.

Exercise content: Students take turns flipping tiles with hidden element symbols and their relevant relative atomic masses, aiming to find matching pairs (figure 3).

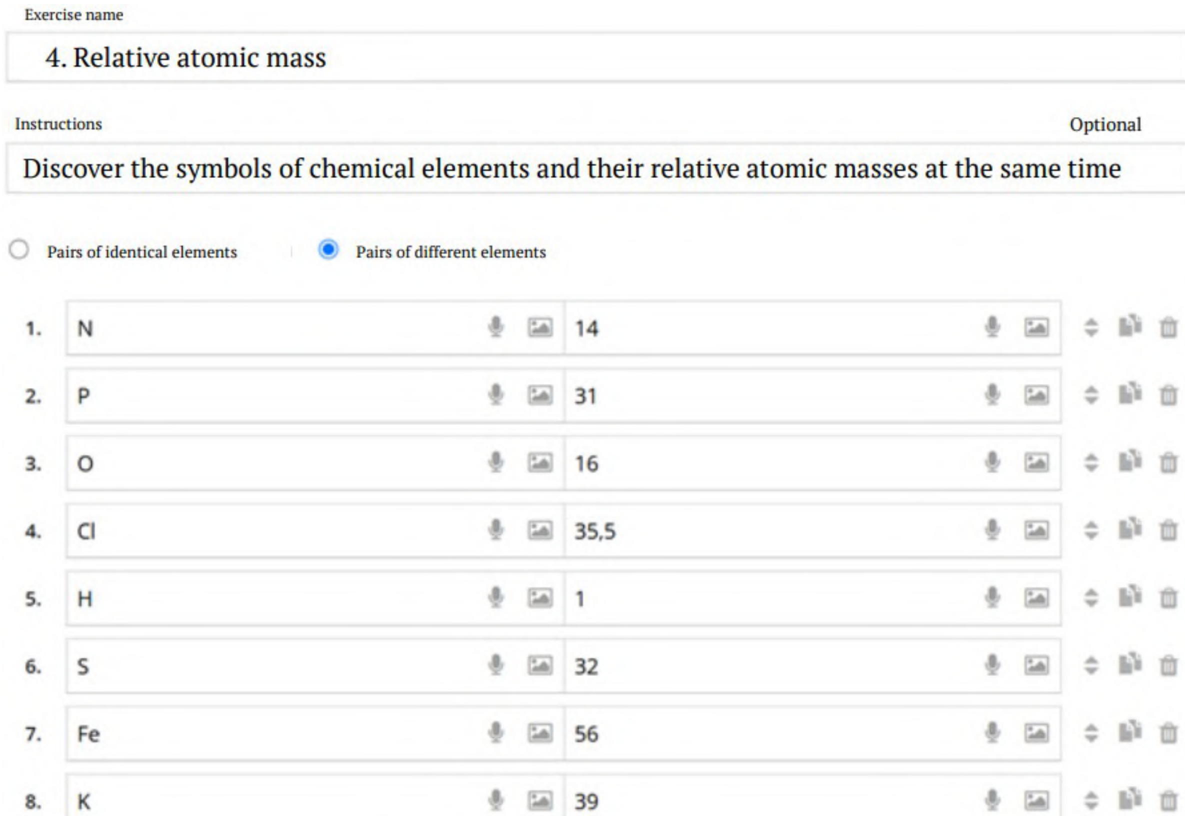
Expected outcomes: Students will memorize the relative atomic masses of key elements in the Periodic Table and train their general memory skills.

Task 4

Lesson topic: Mass fraction of a chemical element in a substance.

Exercise template: "The Correct Order" https://wordwall.net/uk/resource/81577347.

Exercise goal: To learn how to calculate mass fractions of chemical elements in their compounds.



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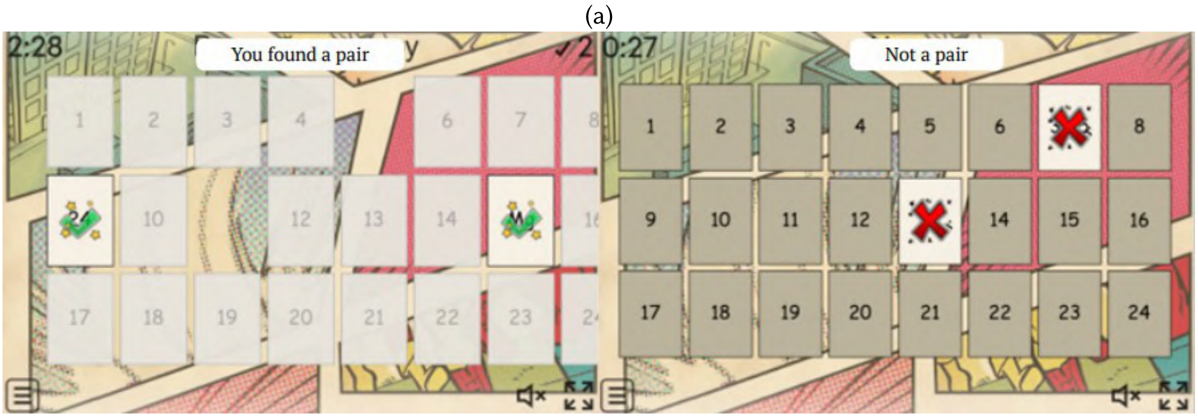

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Figure 3: Interactive exercise "Relative atomic mass": (a) exercise editing; (b) exercise completion.

Exercise content: Students calculate the mass fractions of oxygen in given compounds and arrange them in order (figure 4).

Expected outcomes: Students will practice calculating mass fractions of elements in compounds and improve their ability to order numerical values sequentially.

Task 5 *Lesson topic*: Amount of substance.

Exercise template: "Label Diagram" https://wordwall.net/uk/resource/81585662

Exercise goal: To learn how to solve problems related to the subject.

Exercise content: Students drag labels to complete a table with the calculated data that is necessary (figure 5).

Expected outcomes: Students will learn to calculate the number of structural particles in a given substance portion.

Task 6 *Lesson topic*: Carbon dioxide and carbon monoxide.

Exercise template: "Airplane" https://wordwall.net/uk/resource/82705652

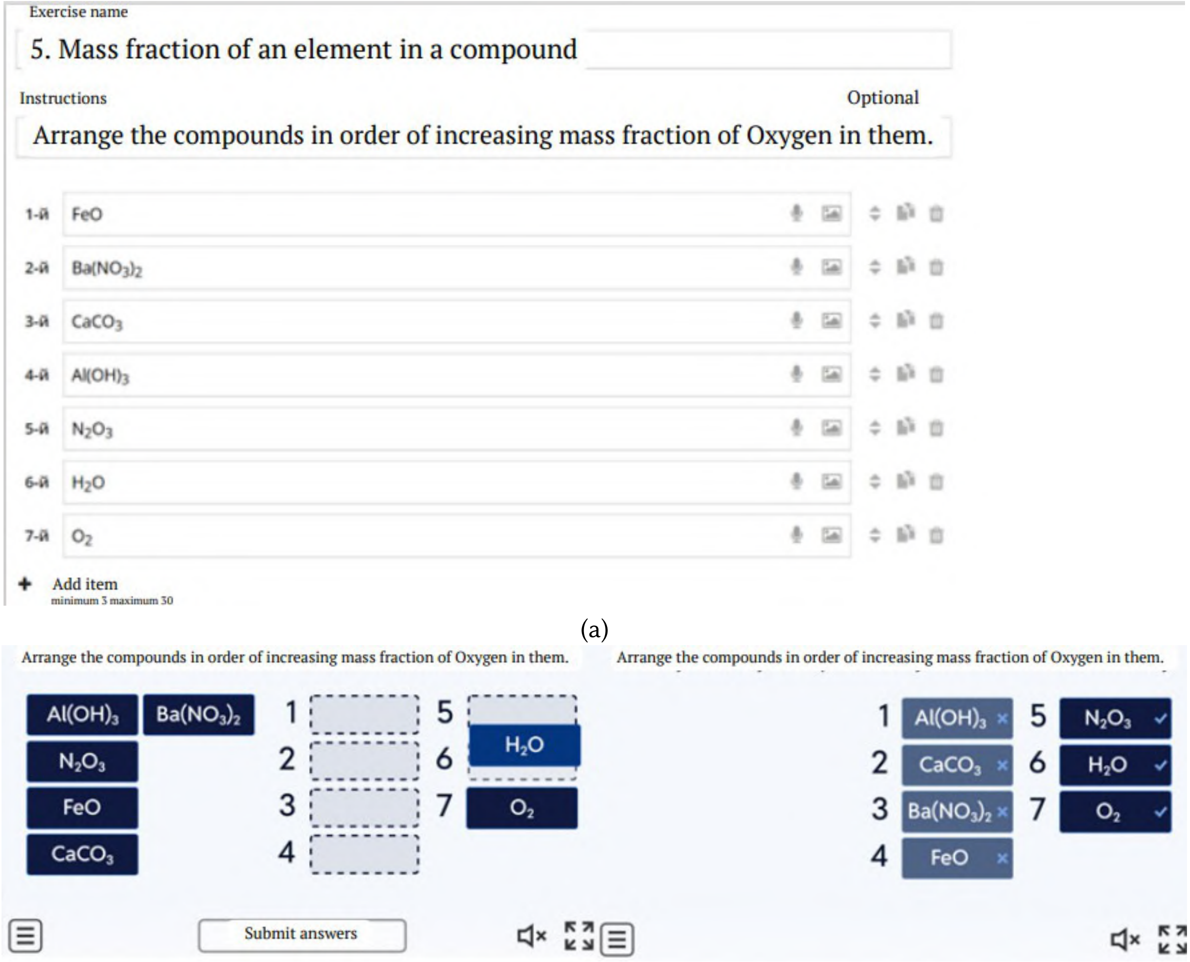

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Figure 4: Interactive exercise “Mass fraction of ab element in a compund”: (a) exercise editing; (b) exercise completion.

Exercise goal: To explore the properties of carbon dioxide and carbon monoxide.

Exercise content: Students navigate an airplane into a cloud that corresponds to the gas, the property of which is described (figure 6).

Expected outcomes: Students will understand the differences between the properties of carbon dioxide and carbon monoxide.

Task 7 *Lesson topic*: Methane.

Exercise template: “Crossword Puzzle” https://wordwall.net/uk/resource/82795306.

Exercise goal: To memorize key concepts related to the “Methane” topic.

Exercise content: Students uncover cells and answer questions (figure 7).

Expected outcomes: Students will remember fundamental concepts related to the topic and be able to explain them in the future.

Task 8 *Lesson topic*: Atomic structure. The Periodic Table

Exercise template: “Quiz Game” https://wordwall.net/uk/resource/82836836.

Exercise goal: To reinforce knowledge about atomic structure and element placement in the Periodic Table.

Exercise content: Students answer questions related to atomic structure and the Periodic Table (figure 8).

Expected outcomes: Students will recall previously studied material interactively and have opportunities for teamwork if the game is performed as a group activity.

The developed tasks are being trialed by 8th-grade students from pilot schools across Ukraine.

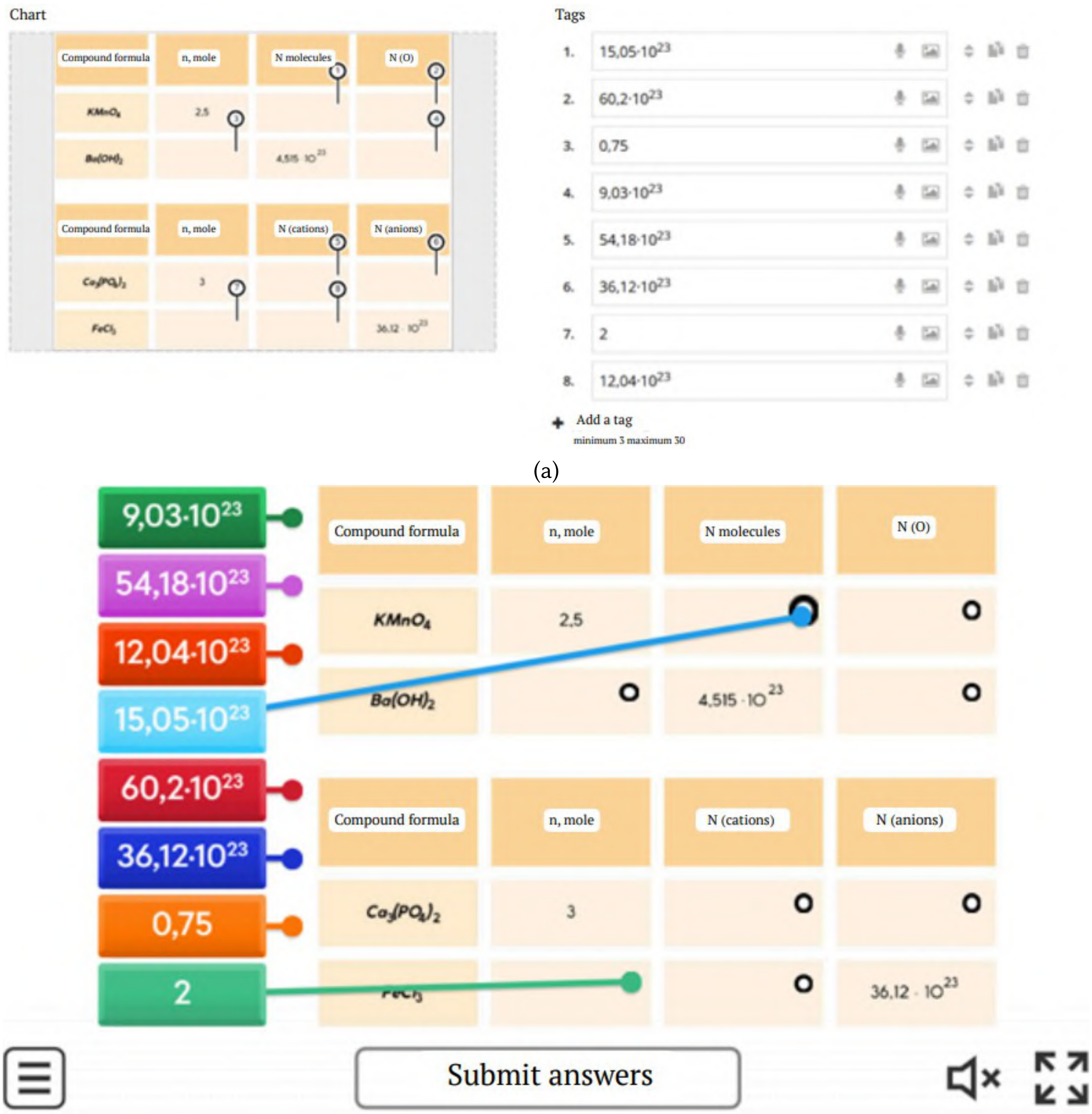

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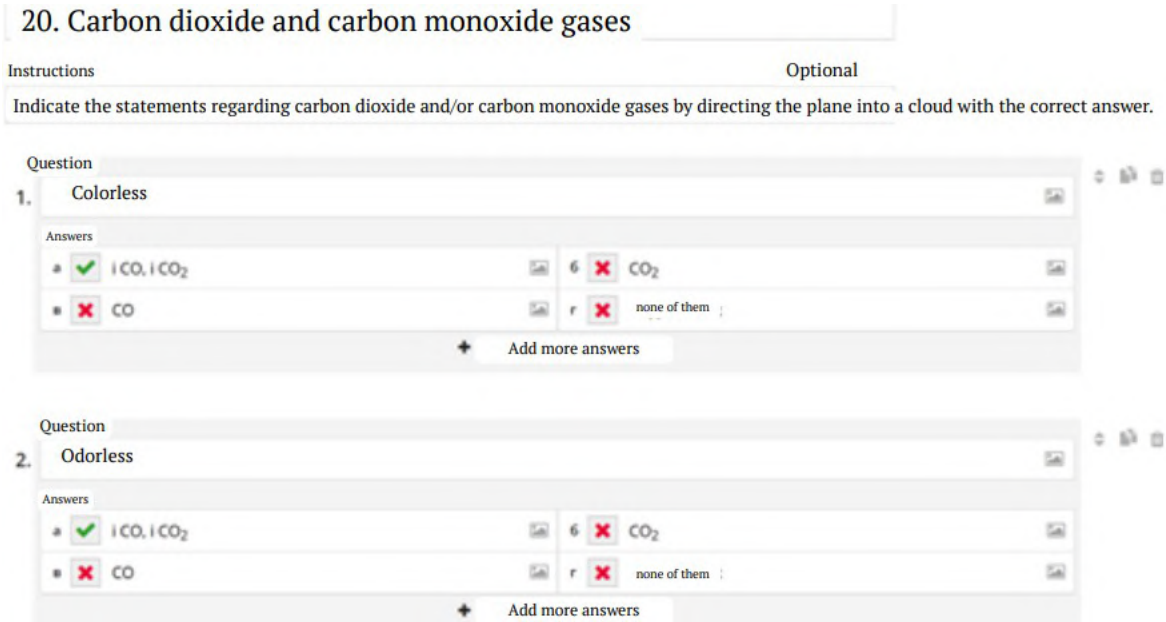
Figure 5: Interactive exercise "Amount of substance (atoms, molecules, ions)": (a) exercise editing; (b) exercise completion.

Seven general secondary education establishments from five regions of Ukraine (Ivano-Frankivsk, Kyiv, Ternopil, Kherson, and Chernivtsi), seven chemistry teachers, and 288 8th-grade students of the New Ukrainian School are participating in the trial.

Since the developed exercises are part of an interactive add-on to the chemistry textbook, the trial was performed along with the pilot testing of the "Chemistry. 8th Grade" textbook (authors: L. Midak, O. Kuzyshyn, Ju. Pahomov, and Kh. Buzhdyhan), in accordance with the Procedure for the Trial of Educational Literature for General Secondary Education Establishments, following the principles of independence, professionalism, objectivity, and impartiality. The trial of this add-on consists of two stages:

1. Familiarization with the types of tasks, assessment of their usability during the lessons, and evaluation of how students perceive the developed exercises;
2. Studying the effectiveness of applying the interactive add-on developed on the Wordwall platform.



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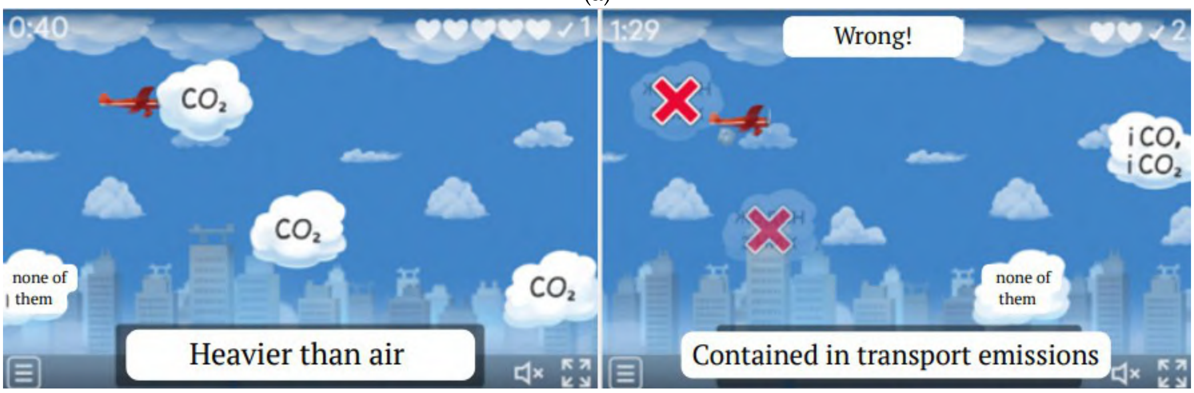

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Figure 6: Interactive exercise "Carbon dioxide and carbon monoxide gases": (a) exercise editing; (b) exercise completion.

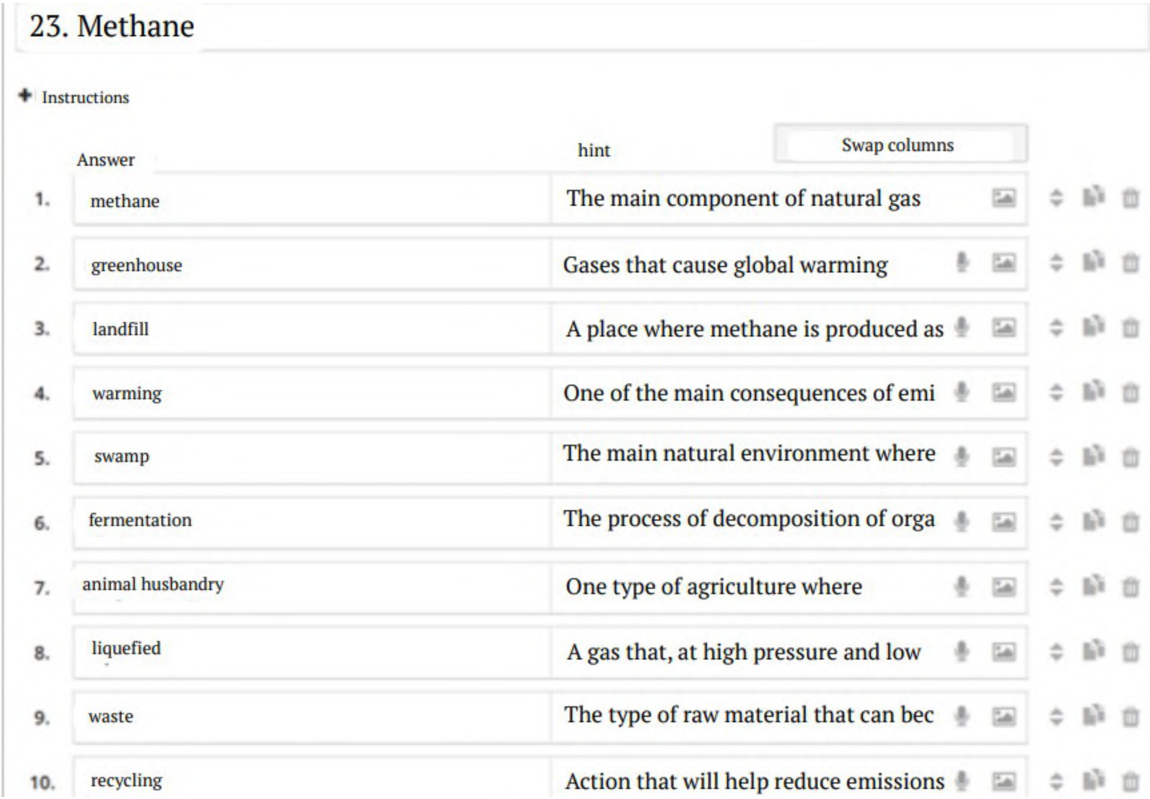
In the first stage of the trial, chemistry lessons were structured using the developed interactive exercises. Students actively engaged in completing the tasks, discussed the results, and received feedback from the teacher.

Teacher feedback was collected via Google Forms created by the Ukrainian Institute of Education Development, in accordance with the Procedure for the Trial of Educational Literature for General Secondary Education Establishments, surveyed the teachers that took part in conducting the trial via Google Forms. The content of the interactive tasks was qualitatively assessed by the participating teachers on the following criteria:

- Didactic tasks are clearly structured (yes / no / other response).
- Tasks/types of educational activities are diverse and understandable (yes / no / other response).
- Didactic methods/techniques are flexible in terms of implementing the interactive study (yes / no / other response).
- Does the content of the exercises correspond to the age characteristics of the students? (yes / no / other response).

Survey results for all criteria: **yes – 7; no – 0**.

Teachers confirmed that the exercises vary in format (quizzes, matching, charts, recognition, sorting, etc.) and are appropriate for the age group of 8th-grade students.



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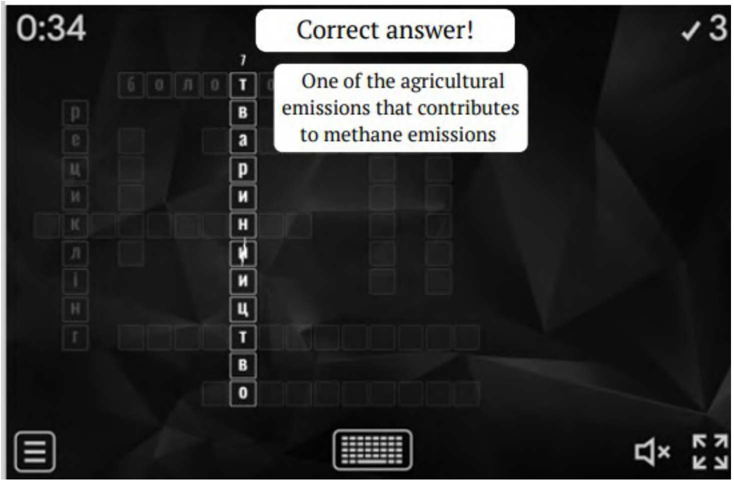

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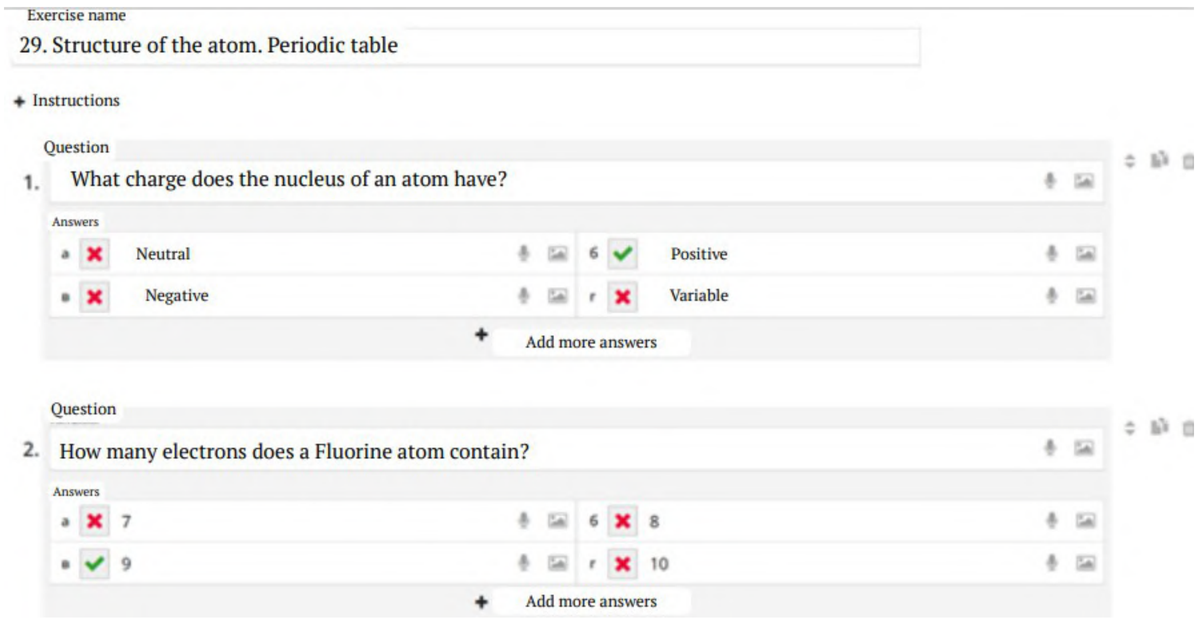
Figure 7: Interactive exercise "Methane": (a) exercise editing; (b) exercise completion.

The results of the diagnostic assessments from the first stage of the trial on the topic "Understanding Quantitative Chemical Laws" showed (figure 9) that 2.2 % of students were at the initial level of academic achievement, 24.6 % at the average level, 54.8 % at the sufficient level, and 18.4 % at the high level. Compared to the entrance assessment results, the number of students at the initial level decreased by 7 %, while those at the sufficient level increased by 10 %.

Quite notable students' progress was particularly evident in topics involving calculations: "Principles of Naming and Building Binary Compounds", "Amount of Substance", and "Relative Atomic Mass". No significant gaps in students'; understanding of the material were identified at this stage.

According to the survey results, 5 out of 7 teachers described the interactive supplement as a "successful pedagogical discovery" for the 8th-grade chemistry textbook, since the interactive exercises promote the development of students' basic capabilities, increase motivation to study, and enhance



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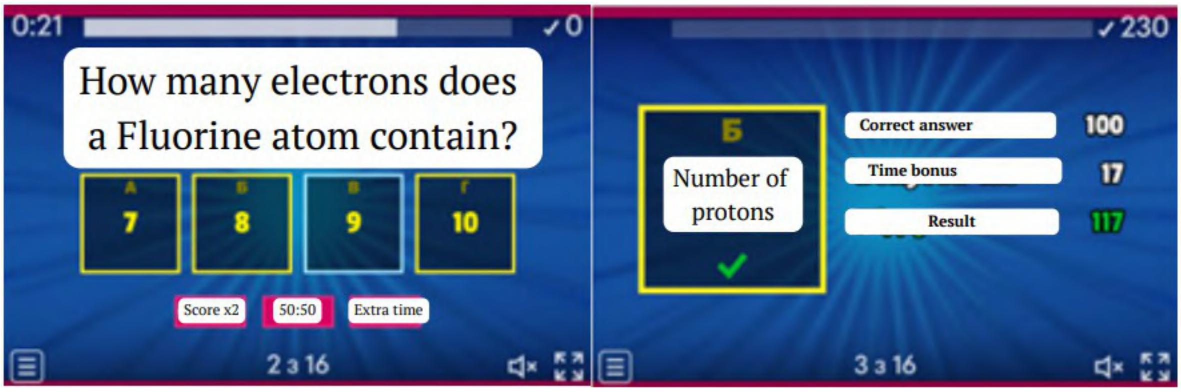

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Figure 8: Interactive exercise "Structure of the atom. Periodic table": (a) exercise editing; (b) exercise completion.

their cognitive skills and creative thinking.

The second stage of the trial is ongoing.

4. Conclusions

The conducted research has demonstrated that the Wordwall platform is an effective tool for modernizing the learning process in chemistry education. Its implementaion makes lessons more engaging and efficient, contributing to improved learning quality and the development of key students' skills.

Using Wordwall fosters the development of students' digital competencies, such as information retrieval, data analysis, and collaboration in an online environment; it also ensures equal access to educational materials regardless of students' locations. Assignments can be completed both in the classroom and at home, which is particularly important in the context of quarantine restrictions or remote education.

The integration of interactive exercises through Wordwall has increased students' interest in the subject, making chemistry lessons more dynamic and interactive.

To assess the effectiveness of the developed interactive tool on the Wordwall platform, it would be advisable to evaluate students' average academic performance after the second stage of testing and compare it with the results of the initial assessment. Expanding the use of Wordwall in chemistry

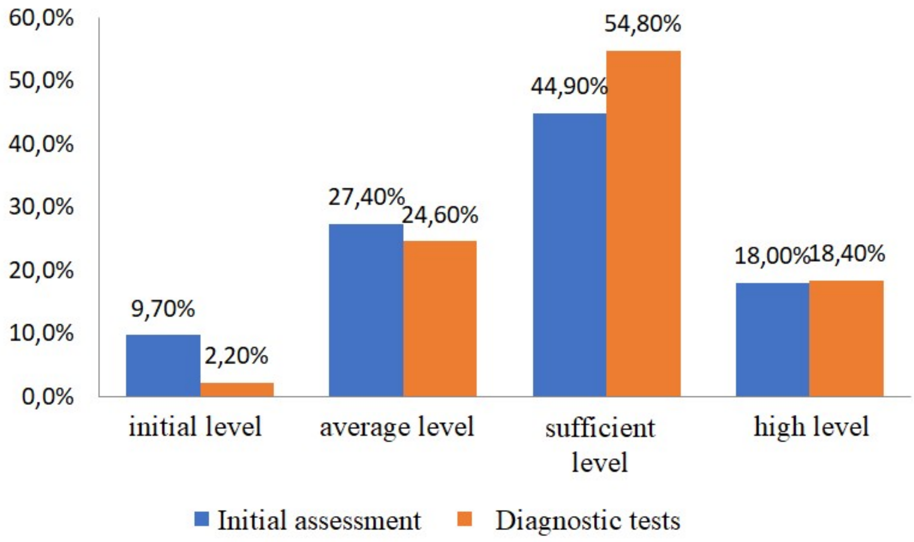

Figure 9: Results of entry assessments and diagnostic tests.

education is recommended. Also, continuing the research on the platform's effectiveness with students of different age groups in the study of other natural science subjects is a must.

The New Ukrainian School concept emphasizes a competency-based approach to education, the integration of digital technologies, and individualized approach to each student. This study has shown that Wordwall meets these requirements, enabling the implementation of key NUS objectives into the chemistry education.

Author contributions

Conceptualization, Liliia Ya. Midak; methodology, Liliia Ya. Midak and Olga V. Kuzyshyn; software, Khrystyna V. Buzhdyhan and Ivan V. Kravets; validation, Khrystyna V. Buzhdyhan and Ivan V. Kravets and Yurii D. Pahomov writing – original draft preparation, Liliia Ya. Midak and Khrystyna V. Buzhdyhan and Olga V. Kuzyshyn; writing—review and editing, Liliia Ya. Midak and Olga V. Kuzyshyn. All authors have read and agreed to the published version of the manuscript.

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Data availability statement

This study used third party data made available under licence that the author does not have permission to share. Requests to access the data should be directed to the Ukrainian Institute of Education Development at https://uied.org.ua/contacts-ua/.

Conflicts of interest

The authors declare no conflict of interest.

Declaration on Generative AI

The authors have not employed any generative AI tools.

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Differential effects of game-based learning platforms on ESL university students: a comparative analysis of Kahoot, Jeopardy, and Bamboozle through the lens of Self-Determination Theory

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Abstract

Game-based learning platforms have emerged as transformative tools in English as a Second Language (ESL) education, yet comparative analyses of their differential effects remain scarce. This mixed-methods study investigates Turkish university students' ($N = 45$) attitudes toward three prominent platforms – Kahoot, Jeopardy, and Bamboozle – through the theoretical framework of Self-Determination Theory (SDT). Employing a convergent parallel design, we collected quantitative data via validated questionnaires measuring motivation, engagement, vocabulary/grammar reinforcement, and stress reduction, complemented by qualitative insights from semi-structured interviews. Kruskal-Wallis H tests revealed nuanced platform-specific effects: Kahoot excelled in fostering intrinsic motivation (91% agreement) and participation (87%), Jeopardy provided structured content review with moderate engagement (82% motivation), while Bamboozle uniquely addressed emotional well-being (84% stress relief). Mann-Whitney U tests indicated no significant gender or proficiency-based differences, suggesting universal applicability across diverse learner profiles. Structural equation modeling revealed that platform choice mediated the relationship between autonomy support and learning outcomes ($\beta = 0.42$, $p < .001$). These findings extend SDT by demonstrating how different gamification mechanics satisfy distinct psychological needs, with implications for adaptive learning design. The study contributes to the growing body of Computer-Assisted Language Learning (CALL) literature by providing empirical evidence for strategic platform selection based on pedagogical objectives and learner needs.

Keywords

game-based learning, ESL education, Self-Determination Theory, Kahoot, comparative analysis, motivation, digital pedagogy

1. Introduction

The integration of digital game-based learning (DGBL) platforms in language education represents a paradigm shift from traditional pedagogical approaches to technology-enhanced, learner-centered environments [1, 2]. As educational institutions globally embrace digital transformation, understanding the differential effects of various gamification platforms becomes crucial for optimizing language learning outcomes [3]. While substantial research has examined individual platforms, particularly Kahoot [4, 5], comparative analyses that illuminate platform-specific affordances remain notably absent from the literature.

The Turkish higher education context presents a unique setting for investigating DGBL effectiveness, characterized by rapid technological adoption alongside traditional pedagogical values [6]. Turkish ESL learners face distinct challenges, including limited authentic language exposure and motivation maintenance in formal educational settings. This study addresses these challenges by examining how different game mechanics align with learner needs and psychological states.

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Self-Determination Theory [7] provides a robust theoretical framework for understanding motivation in gamified learning environments. SDT posits that intrinsic motivation flourishes when three basic psychological needs are satisfied: autonomy (the need for volition and self-direction), competence (the need for effectiveness and mastery), and relatedness (the need for connection and belonging). Different gamification platforms may differentially support these needs through their unique design features and interaction patterns [8].

2. Theoretical framework and literature review

2.1. Self-Determination Theory in digital language learning

Self-Determination Theory offers a multidimensional perspective on motivation that transcends the traditional intrinsic-extrinsic dichotomy [7]. In digital learning environments, SDT's relevance intensifies as technology mediates the satisfaction of psychological needs in novel ways [9]. Recent meta-analyses demonstrate that gamification elements can enhance autonomous motivation when aligned with SDT principles [10].

The autonomy dimension manifests in gamified platforms through choice architecture and personalization features. Heilman et al. [11] found that allowing learners to select topics based on personal interest significantly enhanced vocabulary acquisition, suggesting that even minimal autonomy support can trigger motivational benefits. Competence needs are addressed through progressive difficulty, immediate feedback, and achievement systems that scaffold learning [12]. Relatedness emerges through collaborative features, leaderboards, and social comparison mechanisms, though these can produce differential effects based on individual differences [13].

Critically, SDT suggests that external regulations (such as points and badges) can be internalized along a continuum, potentially supporting or undermining intrinsic motivation depending on implementation [14]. This theoretical nuance is particularly relevant for understanding how different platforms' reward structures influence sustained engagement.

2.2. Comparative analysis of game-based learning platforms

Kahoot's dominance in educational gamification research reflects its widespread adoption and distinctive features [2]. The platform's synchronous, competitive format creates what Licorish et al. [4] term "energized engagement" – a heightened state of attention and participation driven by time pressure and social comparison. Meta-analytic evidence suggests moderate to large effect sizes for Kahoot on learning outcomes ($d = 0.77$), with particularly strong effects on motivation ($d = 0.96$) and retention ($d = 1.49$) [3].

However, the competitive element produces paradoxical effects. While competition enhances engagement for some learners, it can induce anxiety and surface-level processing in others [15]. Alawadhi and Abu-Ayyash [16] found that Emirati students appreciated Kahoot's motivational impact but reported stress from the speed-based scoring system. This tension highlights the importance of considering individual differences in competitive orientation when implementing Kahoot.

Recent innovations in Kahoot's design, including team modes and formative assessment features, address some limitations while maintaining core engagement mechanics [17]. The platform's effectiveness appears contingent on pedagogical integration rather than mere technological adoption [18].

Digital adaptations of Jeopardy leverage familiar game show mechanics to create engaging review sessions [19]. Unlike Kahoot's rapid-fire format, Jeopardy emphasizes strategic thinking through point wagering and category selection. This design affords deeper cognitive processing but may reduce the immediate excitement associated with time-pressured responses.

Limited empirical research on educational Jeopardy implementations represents a significant gap. Available studies suggest moderate effectiveness for content review and collaborative learning [20], but comparative analyses with other platforms remain scarce. The platform's potential for fostering metacognitive skills through strategic decision-making warrants further investigation.

Bamboozle's emergence as an educational platform reflects evolving preferences for customizable, collaborative gaming experiences [21]. The platform's team-based structure and varied game modes offer flexibility absent in more rigid platforms. Preliminary evidence suggests Bamboozle effectively reduces anxiety while maintaining engagement, potentially serving learners who find competitive formats overwhelming.

The platform's relative novelty in academic literature limits comprehensive evaluation. Initial studies indicate promise for vocabulary acquisition and collaborative skill development, but systematic comparisons with established platforms are needed to validate these observations.

2.3. Motivational dynamics in ESL contexts

Language learning motivation exhibits unique characteristics that distinguish it from general academic motivation [7]. The L2 Motivational Self System, comprising the Ideal L2 self, Ought-to L2 self, and L2 Learning Experience, provides a framework for understanding how gamification influences language-specific motivational processes [22].

Recent research demonstrates complex relationships between teacher support, peer support, and L2 engagement, with gamification potentially mediating these relationships [23, 24]. The social dimension of language learning makes collaborative and competitive game elements particularly salient. Kim and Kim [25] found that online community engagement through gamified platforms significantly influenced ESP students' motivational orientations, with differential effects based on proficiency levels.

Cultural factors also shape motivational responses to gamification. Asian educational contexts, characterized by collectivist values and examination pressure, may produce distinct patterns of engagement with competitive versus collaborative game mechanics [26, 27]. Understanding these cultural nuances is essential for interpreting findings from specific national contexts.

2.4. Research gaps and study objectives

Despite extensive research on individual platforms, several critical gaps persist:

1. *Comparative empirical studies*: Direct comparisons of multiple platforms within identical pedagogical contexts remain rare [28].
2. *Theoretical integration*: Few studies explicitly connect platform features to established motivational theories [29].
3. *Individual differences*: The moderating role of learner characteristics on platform effectiveness requires systematic investigation [30].
4. *Emotional dimensions*: Beyond motivation and achievement, platforms' effects on stress, anxiety, and well-being deserve attention [31].

This study addresses these gaps through a theoretically grounded, comparative analysis of three platforms, examining both cognitive and affective outcomes while considering individual difference variables.

3. Research questions

Building on identified gaps and theoretical foundations, this study addresses:

RQ1: What are ESL university students' differential attitudes toward Kahoot, Jeopardy, and Bamboozle in language learning contexts?

RQ2: How do the three platforms differ in their effects on motivation, vocabulary/grammar reinforcement, stress relief, and participation, as understood through Self-Determination Theory?

RQ3: To what extent do gender and language proficiency moderate platform preferences and perceived effectiveness?

RQ4: What platform-specific features emerge as critical for satisfying learners' psychological needs for autonomy, competence, and relatedness?

4. Methodology

4.1. Research design

This study employed a convergent parallel mixed-methods design [32], integrating quantitative and qualitative data to provide comprehensive insights into platform effects. The design's strength lies in triangulation, allowing validation of quantitative patterns through qualitative exploration of underlying mechanisms. Data collection occurred simultaneously, with integration during the interpretation phase.

4.2. Participants and context

Participants comprised 45 students (19 males, 26 females) enrolled in a mandatory English preparatory program at two Turkish state universities during the 2024–2025 academic year. Ages ranged from 18 to 22 years ($M = 19.4$, $SD = 1.2$). The sample represented diverse academic disciplines: Engineering (40%), Social Sciences (33%), and Health Sciences (27%). Language proficiency levels, assessed via institutional placement tests aligned with the Common European Framework of Reference (CEFR), included A2 (31%), B1 (42%), and B2 (27%) levels.

Convenience sampling was employed due to institutional access constraints [32]. While limiting generalizability, this approach facilitated in-depth investigation within authentic educational settings. Post-hoc power analysis indicated adequate power (0.82) for detecting medium effect sizes with the obtained sample.

4.3. Intervention design

The intervention spanned eight weeks, with each platform implemented for concentrated two-week periods followed by a comparison week. This rotation design minimized order effects while allowing sufficient exposure for attitude formation. Each platform session lasted 20 minutes, integrated into regular 90-minute classes twice weekly.

Platform implementation followed standardized protocols:

- **Kahoot**: Quiz games covering weekly vocabulary and grammar topics, utilizing both individual and team modes.
- **Jeopardy**: Review sessions with categories spanning difficulty levels, implemented via Jeopardy-Labs.
- **Bamboozle**: Varied game modes including matching, multiple choice, and open-ended questions, emphasizing collaboration.

Content alignment across platforms ensured comparability, with identical learning objectives targeted through platform-specific mechanics.

4.4. Data collection instruments

4.4.1. Quantitative measures

The primary instrument adapted validated scales from Wei and Moyer [33] and Licorish et al. [4], comprising 40 Likert-scale items (1 = strongly disagree, 5 = strongly agree) measuring four dimensions per platform:

1. **Motivational impact** (10 items, $\alpha = 0.89$): "Using [Platform] increases my desire to learn English".
2. **Learning effectiveness** (10 items, $\alpha = 0.87$): "[Platform] helps me remember vocabulary better".
3. **Engagement quality** (10 items, $\alpha = 0.91$): "I feel fully absorbed when using [Platform]".
4. **Emotional response** (10 items, $\alpha = 0.85$): "[Platform] reduces my anxiety about making mistakes".

Confirmatory factor analysis supported the four-factor structure ($\chi^2/df = 2.14$, CFI = 0.93, RMSEA = 0.06), indicating acceptable model fit.

4.4.2. Qualitative measures

Semi-structured interviews with 12 purposefully selected participants (representing high, medium, and low engagement levels) explored experiences in depth. The interview protocol, developed through expert consultation and pilot testing, addressed:

- Platform-specific experiences and preferences.
- Perceived learning benefits and challenges.
- Emotional responses and stress levels.
- Suggestions for improvement.

Interviews lasted 30–45 minutes, were conducted in participants' preferred language (Turkish or English), and were audio-recorded with consent.

4.5. Data analysis procedures

4.5.1. Quantitative analysis

Statistical analyses employed SPSS 28.0 and AMOS 26.0, following a hierarchical approach:

1. Descriptive statistics characterized response distributions and identified outliers.
2. Reliability analysis confirmed scale internal consistency.
3. Normality testing (Shapiro-Wilk) indicated non-normal distributions, justifying non-parametric approaches.
4. Kruskal-Wallis H tests examined platform differences across dimensions.
5. Mann-Whitney U tests explored gender effects.
6. Effect sizes (Cohen's d and r) quantified practical significance.
7. Structural equation modeling tested mediational pathways between SDT constructs and outcomes.

4.5.2. Qualitative analysis

Interview transcripts underwent thematic analysis following Cohen et al. [32] framework:

1. Familiarization through repeated reading.
2. Initial coding using both inductive and deductive approaches.
3. Theme development through code clustering.
4. Theme refinement via constant comparison.
5. Final theme definition and exemplar selection.

Two independent coders achieved substantial inter-rater reliability (Cohen's $\kappa = 0.83$), with discrepancies resolved through discussion.

4.6. Ethical considerations

The study received institutional ethics approval. Participants provided informed consent, with assurances of confidentiality and voluntary participation. Platform exposure formed part of regular curriculum, minimizing ethical concerns about differential treatment.

5. Results

5.1. RQ1: Differential student attitudes across platforms

Table 1 presents aggregated attitude scores across platforms, revealing distinct preference patterns.

Kahoot emerged as the most positively perceived platform, though differences were modest.

Analysis of specific dimensions revealed platform strengths and limitations (table 2).

Kahoot dominated motivational and engagement dimensions, while Bamboozle excelled in emotional support. Jeopardy showed consistent moderate scores without distinctive strengths.

Table 1
Overall attitude scores by platform.

Platform	Mean	SD	Median	IQR	Preference rank
Kahoot	4.12	0.68	4.20	0.85	1
Bamboozle	3.89	0.74	3.95	0.92	2
Jeopardy	3.71	0.81	3.75	1.05	3

Table 2
Mean scores by platform and dimension.

Dimension	Kahoot	Jeopardy	Bamboozle
Motivation	4.31 (0.72)	3.82 (0.89)	3.95 (0.78)
Learning effectiveness	4.05 (0.81)	3.77 (0.93)	3.68 (0.86)
Engagement quality	4.18 (0.69)	3.64 (0.97)	3.89 (0.83)
Emotional response	3.92 (0.94)	3.61 (1.02)	4.14 (0.71)

Note: Standard deviations in parentheses.

5.2. RQ2: Platform effects through SDT lens

Structural equation modeling revealed differential autonomy support across platforms (figure 1). Kahoot's limited choice architecture ($\beta = 0.28, p < .05$) contrasted with Bamboozle's flexibility ($\beta = 0.51$, $p < .001$).

All platforms supported competence through feedback mechanisms, though with varying effectiveness. Kahoot's immediate feedback strongly predicted perceived competence ($\beta = 0.61$, $p < .001$), while Jeopardy's strategic elements appealed to higher-proficiency learners.

Social dynamics varied markedly across platforms. Kahoot's competitive element produced mixed effects on relatedness, while Bamboozle's collaborative structure consistently fostered connection.

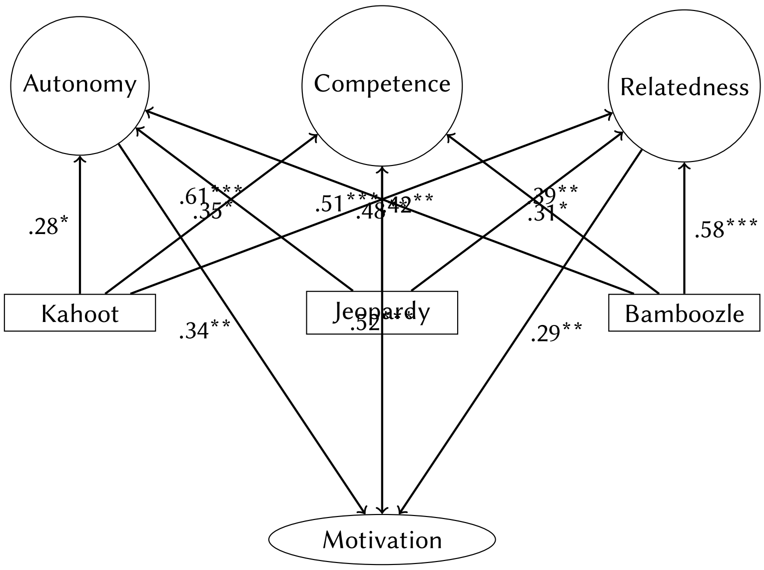

Figure 1: Structural model of platform effects on SDT components and motivation.

Note: $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

5.3. RQ3: Moderating effects of individual differences

Mann-Whitney U tests revealed no significant gender differences in overall platform preferences (table 3). However, qualitative analysis suggested subtle variations in engagement patterns.

Table 3
Gender differences in platform preferences.

Platform	Gender	Mean rank	*U*	*Z*	*p*
Kahoot	Male Female	24.32 22.06	238.5	-0.62	.536
Jeopardy	Male Female	21.84 23.85	230.0	-0.74	.459
Bamboozle	Male Female	22.71 23.21	240.5	-0.53	.596

Kruskal-Wallis tests indicated no significant proficiency-based differences ($H(2) = 2.59$, $p = .274$). However, thematic analysis revealed proficiency-specific preferences.

5.4. RQ4: Critical features for psychological need satisfaction

Thematic analysis identified platform-specific features crucial for SDT components:

- Features supporting autonomy
  - Bamboozle: Question type selection, self-pacing, team role choice.
  - Jeopardy: Category selection, strategic wagering, difficulty choice.
  - Kahoot: Limited to nickname selection and occasional team formation.
- Features supporting competence
  - Kahoot: Immediate feedback, progress visualization, achievement streaks.
  - Jeopardy: Progressive difficulty, strategic success, knowledge demonstration.
  - Bamboozle: Collaborative problem-solving, peer learning, mistake tolerance.
- Features supporting relatedness
  - Bamboozle: Team collaboration, shared success, peer support.
  - Kahoot: Shared excitement, class-wide participation, social recognition.
  - Jeopardy: Team consultation, collective strategy, knowledge sharing.

6. Discussion

6.1. Theoretical implications

Our findings extend Self-Determination Theory by demonstrating how specific gamification mechanics differentially support psychological needs. The structural equation model reveals that competence support most strongly predicts motivation ($\beta = 0.52$), aligning with Maimaiti and Hew [12]'s assertion that mastery experiences drive sustained engagement in digital learning environments. However, our results suggest a more nuanced relationship: competence without autonomy produces fragile motivation vulnerable to performance pressure.

The paradox of Kahoot's popularity despite limited autonomy support challenges simplistic SDT applications. Following Rojabi et al. [14], we propose that intense, short-duration engagement can temporarily override autonomy needs through what might be termed "flow-induced motivation" – a state where immediate absorption supersedes reflective autonomy concerns. This phenomenon warrants theoretical elaboration, potentially expanding SDT to accommodate temporal dynamics in digital environments.

Bamboozle's superior emotional support despite modest learning effectiveness scores suggests that affective dimensions may mediate cognitive outcomes more substantially than current models acknowledge. This finding resonates with Wang and Liu [10]'s work on buoyancy as a mediator between motivation and engagement, implying that emotional scaffolding creates conditions for subsequent learning even when immediate knowledge gains appear limited.

6.2. Practical implications for ESL pedagogy

Our results offer evidence-based guidance for strategic platform selection aligned with pedagogical objectives (table 4).

Table 4
Platform selection guide based on pedagogical objectives.

Primary objective	Recommended platform	Key features	Considerations
Energy and engagement	Kahoot	Competition, music, time pressure	Monitor anxiety levels; provide alternatives for sensitive learners
Deep review	Jeopardy	Strategic thinking, category mastery	Better for intermediate+ levels; requires content familiarity
Anxiety reduction	Bamboozle	Collaboration, self-pacing, team support	May require explicit instruction on collaborative skills
Formative assessment	Kahoot or Bamboozle	Immediate feedback vs. peer discussion	Balance efficiency with depth

Based on our findings and recent literature [34, 35], we propose a cyclical implementation model:

1. Introduction phase: Use Bamboozle to reduce anxiety and build collaborative norms.
2. Practice phase: Employ Kahoot for energized practice and immediate feedback.
3. Consolidation phase: Apply Jeopardy for strategic review and self-assessment.
4. Integration phase: Combine platforms based on daily objectives and learner states.

This progression respects the developmental nature of language learning while maintaining engagement through variety.

6.3. Addressing the challenges

Our study identified several implementation challenges requiring systematic attention:

1. *Technical infrastructure*: Consistent internet connectivity and device access remain prerequisites. Institutions should conduct technical audits before implementation and maintain offline alternatives [36].
2. *Teacher professional development*: Effective gamification requires more than technical competence. Teachers need training in:
   - Recognizing signs of competitive stress.
   - Balancing game elements with learning objectives.
   - Adapting platforms to diverse learner needs.
   - Integrating games within broader pedagogical frameworks.
3. *Assessment validity*: While platforms offer engagement benefits, their assessment validity requires scrutiny. Joyce [37] demonstrated that online formative assessments can predict summative performance, but careful item construction and alignment remain essential.

6.4. Cultural and contextual considerations

The Turkish educational context influenced our findings in ways that merit explicit discussion. The collectivist cultural orientation may explain Bamboozle's strong emotional support ratings, as collaborative success aligns with cultural values. Similarly, the competitive element in Kahoot might produce different effects in more individualistic cultures [27].

The preparatory program context, with its high-stakes implications for university admission, creates unique motivational dynamics. Students' receptiveness to gamification might partially reflect desires for stress relief from traditional assessment pressures. Replication in diverse cultural and institutional contexts would strengthen generalizability claims.

7. Limitations and future directions

Several limitations constrain our findings' interpretability:

1. **Sample size and duration**: While adequate for detecting medium effects, our sample size limited sophisticated moderator analyses. The eight-week duration captured immediate responses but not long-term sustainability. Future research should employ larger samples over extended periods to examine novelty effects and sustained engagement patterns.
2. **Platform implementation variability**: Despite standardization efforts, platforms' inherent differences prevented complete equivalence. Kahoot's distinctive audiovisual elements, Jeopardy's familiar format, and Bamboozle's flexibility introduce confounds beyond controlled variables.
3. **Self-report limitations**: Reliance on self-reported attitudes and motivation may not fully capture actual learning behaviors. Future studies should incorporate objective measures such as eye-tracking, engagement analytics, and longitudinal achievement data [38].
4. **Limited scope of individual differences**: While we examined gender and proficiency, other potentially relevant variables (e.g., technology self-efficacy, gaming experience, learning styles) were not assessed. Kawaguchi and Watkins [39] demonstrated that prior gaming experience significantly influences educational game reception, suggesting important unmeasured variance.

Future research directions emerging from our findings include:

1. Comparative neurophysiological studies examining platforms' differential effects on attention, arousal, and cognitive load using EEG or fNIRS methodologies.
2. Longitudinal investigations tracking motivation trajectories across extended platform exposure, identifying critical periods for novelty decay and intervention.
3. Cross-cultural replications examining how cultural values moderate platform preferences and effectiveness.
4. Adaptive gamification research exploring AI-driven platform selection based on real-time learner states and objectives.
5. Mixed-reality extensions investigating how AR/VR integration might enhance platforms' affordances for language learning [40].

8. Conclusion

This comparative analysis illuminates the complex landscape of game-based learning in ESL education, revealing that platform effectiveness cannot be reduced to simple superiority claims. Instead, our findings support a contingency perspective: optimal platform selection depends on specific pedagogical objectives, learner characteristics, and contextual factors.

Through the lens of Self-Determination Theory, we demonstrated that Kahoot, Jeopardy, and Bamboozle differentially support autonomy, competence, and relatedness, creating distinct motivational profiles. Kahoot's strength in generating immediate engagement and competence feedback makes it ideal for energizing practice sessions, though educators must monitor potential anxiety effects. Jeopardy's strategic elements serve advanced learners seeking cognitive challenge but may overwhelm beginners. Bamboozle's collaborative flexibility and emotional support address affective barriers to learning, though potentially at the cost of immediate achievement gains.

The absence of significant gender and proficiency effects suggests these platforms' broad applicability, though qualitative insights reveal subtle preferences warranting pedagogical attention. The finding that competence support most strongly predicts motivation underscores the importance of careful difficulty calibration and feedback design in gamified learning.

Our study contributes to the growing CALL literature by providing empirical evidence for strategic gamification grounded in motivational theory. As educational technology continues evolving, our framework offers a foundation for evaluating emerging platforms through the lens of psychological need satisfaction rather than surface features alone.

The implications extend beyond immediate platform selection to broader questions about technology's role in language education. As Henry [8] argues, motivation in digital environments emerges through complex interactions between learner agency, technological affordances, and pedagogical mediation. Our findings support this interactionist perspective while highlighting the need for adaptive, learner-centered approaches to educational gamification.

Moving forward, the field requires more sophisticated theoretical models that account for the temporal, cultural, and individual dynamics of gamified learning. The integration of learning analytics, artificial intelligence, and adaptive systems promises personalized gamification experiences that dynamically respond to learner states. However, as our study demonstrates, technological sophistication must be balanced with attention to fundamental psychological needs and pedagogical principles.

In conclusion, effective game-based language learning emerges not from platform features alone but from thoughtful integration that aligns technological affordances with learner needs and educational objectives. As educators navigate an expanding array of digital tools, our findings offer empirically grounded guidance for creating engaging, supportive, and effective language learning environments that honor both the playful potential and serious purpose of educational gamification.

Declaration on Generative AI

During the preparation of this work, the author used ChatGPT to sentence polishing. After using this tool, the author reviewed and edited the content as needed and took full responsibility for the publication's content.

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Digital history pedagogy in higher education: a PRISMA-compliant systematic review of empirical evidence (2011–2025)

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Abstract

Background: The integration of digital technologies into history education represents a fundamental transformation in pedagogical practice, yet comprehensive evidence synthesis regarding its effectiveness remains absent from the scholarly literature. This systematic review addresses this critical gap by evaluating empirical evidence on digital history teaching effectiveness at the undergraduate level.

Methods: Following PRISMA 2020 guidelines, we conducted a systematic search of the Scopus database spanning 2013 to 2025. Inclusion criteria encompassed empirical studies involving undergraduate students (aged 18+) that evaluated digital interventions in history education. Two independent reviewers performed screening and data extraction, with discrepancies resolved through consensus.

Results: From 46 initially identified records, six studies met inclusion criteria after rigorous screening. The included studies employed diverse digital interventions ranging from collaborative wiki platforms to augmented reality applications. Analysis revealed consistent positive effects on student engagement (100% of studies), moderate improvements in historical knowledge acquisition (67% of studies), and enhanced development of critical thinking skills through primary source analysis. Notably, studies incorporating TPACK (Technological Pedagogical Content Knowledge) frameworks demonstrated superior outcomes in both cognitive and affective domains.

Conclusions: Digital technologies demonstrate substantial potential for enhancing history education, particularly in fostering student engagement and developing analytical capabilities. However, the evidence base remains limited by methodological heterogeneity and absence of long-term follow-up studies. Future research should prioritize randomized controlled designs and standardized outcome measures to establish more robust evidence for digital history pedagogy.

Keywords

digital history, undergraduate education, systematic review, PRISMA, pedagogical technology, historical thinking, TPACK framework, digital humanities

1. Introduction

1.1. Rationale

The transformation of historical scholarship through digital methodologies has fundamentally altered both research practices and pedagogical approaches in higher education institutions worldwide. Digital history, defined as the systematic application of computational tools and methods to historical research, teaching, and dissemination, has evolved from a peripheral specialization to an integral component of contemporary historical practice [1, 2]. This evolution reflects broader shifts in information accessibility, student learning preferences, and the competencies required for twenty-first-century historical work.

Contemporary undergraduate students inhabit an information ecosystem characterized by unprecedented access to digitized primary sources, computational analysis tools, and multimedia presentation platforms. Research indicates that strategic integration of digital technologies in history courses facilitates deeper engagement with historical materials while developing transferable analytical competencies [3, 4]. The proliferation of digital archives has democratized access to primary sources previously

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confined to specialized repositories, enabling students to engage directly with historical evidence regardless of geographical constraints [5, 6].

Empirical investigations demonstrate measurable benefits when digital tools are thoughtfully integrated into history curricula. Students participating in collaborative digital history projects exhibit enhanced critical thinking capabilities, improved source evaluation skills, and more sophisticated understanding of historical narratives as constructed interpretations rather than fixed truths [7, 8]. Project-based learning incorporating digital methodologies has proven particularly effective in developing what researchers term "historical empathy" – the capacity to understand past actors within their specific temporal and cultural contexts [9, 10].

The pedagogical frameworks supporting digital history education have matured considerably. The TPACK (Technological Pedagogical Content Knowledge) model provides a theoretical foundation for understanding how technology, pedagogy, and content knowledge intersect in effective teaching practice [11, 12]. Implementation of the DEPSWALIC digital competency framework has demonstrated measurable improvements in both instructor confidence and student learning outcomes across diverse institutional contexts [13, 14]. These frameworks address the critical challenge of ensuring that technological integration enhances rather than supplants fundamental historical thinking skills.

Despite growing implementation and anecdotal evidence of effectiveness, no comprehensive systematic review has synthesized empirical findings regarding digital history pedagogy at the undergraduate level. This absence is particularly notable given the substantial institutional investments in digital infrastructure and the ongoing debates regarding optimal implementation strategies. The diversity of approaches – from gamification and virtual reality applications to collaborative writing platforms and GIS mapping – further underscores the need for systematic evaluation of relative effectiveness across different methodological approaches.

1.2. Objectives

This systematic review aims to address primary research question: *How effective is teaching digital history to students compared to non-digital methods of teaching history in terms of improving learning outcomes?*

Subsidiary research questions:

1. **By student categories:** Does the status of a digital history course (mandatory or elective) affect its effectiveness?

2. **By course status:** Which specific digital tools and technologies for teaching history demonstrate the highest effectiveness?

3. **By teaching tools:** Which effectiveness indicators (knowledge, skills, motivation, engagement) are most sensitive to the impact of digital methods of teaching history?

4. **By intervention duration:** Does the duration of digital methods use affect their effectiveness in teaching history?

2. Methods

2.1. Protocol and registration

This systematic review adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement [15]. While no formal protocol was registered in a public repository such as PROSPERO, the review methodology was established a priori, with eligibility criteria, search strategy, and data extraction procedures determined before database searching commenced. This approach ensures methodological transparency while acknowledging the exploratory nature of this initial systematic synthesis in digital history pedagogy.

2.2. Eligibility criteria

Studies were evaluated against predetermined inclusion and exclusion criteria developed through iterative refinement based on preliminary scoping searches.

2.2.1. Inclusion criteria

Eligible studies satisfied the following requirements:

- **Population:** Undergraduate students enrolled in history courses at accredited higher education institutions, with participants aged 18 years or older. Studies including mixed populations were eligible if undergraduate data could be extracted separately.
- **Intervention:** Any digital technology intervention designed to enhance history education, encompassing but not limited to: collaborative writing platforms, digital archives and databases, geographic information systems (GIS), virtual reality environments, gamification elements, digital storytelling tools, or computational text analysis methods. Interventions required substantive integration into course design rather than supplementary use.
- **Comparator:** Studies employing traditional teaching methods as comparators, alternative digital interventions, or pre-post designs without external controls were all considered eligible, reflecting the diversity of research designs in educational technology research.
- **Outcomes:** Primary outcomes included measures of student engagement (behavioral, cognitive, or affective), historical knowledge acquisition, critical thinking skills, source analysis capabilities, or digital literacy development. Secondary outcomes encompassed student satisfaction, technological self-efficacy, and collaborative learning indicators.
- **Study design:** Empirical studies employing quantitative, qualitative, or mixed methods approaches. Eligible designs included randomized controlled trials, quasi-experimental studies, cohort studies, case studies with systematic data collection, and phenomenological investigations with rigorous analytical frameworks.
- **Publication parameters:** Peer-reviewed articles, conference proceedings, and book chapters published between January 2011 and July 2025. The starting date corresponds with widespread adoption of Web 2.0 technologies in higher education, while the end date represents the search execution period.

2.2.2. Exclusion criteria

Studies were excluded based on the following parameters:

- Participants below university level (K-12 education) or exclusively graduate students without undergraduate representation.
- Theoretical or conceptual papers lacking empirical data.
- Technology training for educators without student outcome assessment.
- Studies focused on disciplines other than history, even when employing similar digital methodologies.
- Interventions lasting less than two weeks or involving fewer than five participants.
- Publications in languages other than English, reflecting resource constraints rather than linguistic bias.
- Editorial commentaries, book reviews, or conference abstracts without full-text availability.

2.3. Information sources and search strategy

2.3.1. Database selection

Scopus was selected as the primary database due to its comprehensive coverage of peer-reviewed literature across disciplines, including education, history, and information science. The database indexes over 48,000 active titles from more than 5,000 international publishers, providing broader coverage than discipline-specific databases while maintaining quality standards through peer-review requirements. Supplementary searches in Web of Science, ERIC, and Google Scholar were initially planned but ultimately deemed unnecessary given the comprehensive results from Scopus and resource constraints.

2.3.2. Search strategy development

The search strategy underwent iterative refinement through preliminary testing to optimize sensitivity while maintaining precision. The initial search string employed Boolean operators and truncation symbols to capture relevant terminology variations:

```
TITLE-ABS-KEY ( "digital history" AND student* )
```

Search parameters were limited to title, abstract, and keyword fields to balance comprehensiveness with relevance. The search was executed on July 26, 2025, with no date restrictions applied during the search phase.

The search query after corrections looks as follows:

```
TITLE-ABS-KEY
    (
        "digital history"
        AND
        student*
    )
    AND
    (
        LIMIT-TO ( LANGUAGE , "English" )
    )
    AND
    (
        LIMIT-TO ( DOCTYPE , "ar" )
        OR
        LIMIT-TO ( DOCTYPE , "cp" )
        OR
        LIMIT-TO (  DOCTYPE ,  "ch" )
    )
```

2.4. Study selection process

The selection process followed a two-stage screening protocol conducted independently by two reviewers with expertise in digital humanities and educational research.

2.4.1. Stage 1: Title and abstract screening

Initial screening evaluated titles and abstracts against predetermined eligibility criteria. Each record received dual review, with conflicts resolved through discussion. Studies were advanced to full-text review when abstracts provided insufficient information for definitive exclusion.

To automate the research, Claude 4 Opus was used for preliminary analysis. The automated tool was used as an auxiliary means *before* the main screening by two reviewers. All final decisions regarding inclusion/exclusion were made exclusively by human reviewers. Results of Claude 4 Opus's preliminary analysis were fully verified and validated by two reviewers.

This approach to study selection ensured efficient and thorough evaluation of all 46 records while maintaining systematic review quality principles within the resource capabilities of a research project.

At the preliminary screening stage, LLM helps to identify a duplicate – the same study by [16] published in two formats: as a conference proceedings article and as a full journal article. After excluding the duplicate, we got a 45 unique publications for further screening.

To automate article verification, a query was submitted to Claude 4 Sonnet (another Anthropic's model used for processing short texts like paper abstracts):

```
For each of the 45 attached documents, determine which should be excluded from
the review, and why. Output the result as:

BibTeX identifier: reason(s) for exclusion.

Separately output documents that remain.
```

The chatbot's response was verified by the researcher. Based on the response, 28 articles were excluded (appendix A). After researcher verification, 1 document was added to potentially included (appendix B).

2.4.2. Stage 2: Full-text assessment

The next step is attempting to obtain the 17 selected papers, succeeded in obtaining – 15, failed to obtain – 2 (appendix D). Authors were contacted to obtain missing information for two studies, though neither response was received within the review timeline.

Full texts of potentially eligible studies underwent comprehensive evaluation against all inclusion and exclusion criteria using both human and LLM assistance.

The supportive query to Claude 4 Opus was: "*Evaluate the attached article for compliance with inclusion criteria. Indicate whether it should be included in the review or not. If not - indicate the reason.*" Based on LLM responses according to selected inclusion criteria, 3 articles were selected and 12 were rejected. The minimum number of articles in a systematic review is not formally regulated, and 3 studies are acceptable, but this is an extreme case requiring very good justification (for example, if the field is highly specialized or novel). The Cochrane Handbook does not specify a strict minimum but assumes the presence of sufficient data for analysis.

Therefore, it was decided to relax the selection criteria. So the next query was: "*The number of selected articles is too small. What are the options for relaxing the selection criteria to increase the number of selected articles to a minimally acceptable level?*"

The LLM recommendations as follows:

1. "Expand time frame to 2011-2024 → +1 article".
2. "Include master's students +2 articles".
3. "Include descriptive case studies with systematic data collection".

The researcher decided to reject last recommendation. The time frame was expanded to 2011, as this period coincides with the beginning of widespread implementation of digital technologies in education and the appearance of the first systematic studies of digital history. Participant criteria were expanded to include master's students (MA/MEd programs), as in many universities they study alongside bachelor's students in the same history courses, and their experience using digital technologies is relevant for the undergraduate level.

Contact with authors of included studies was not made to obtain or confirm additional information. The decision was based on the fact that all necessary data for completing review maps were available in published research reports, as well as limited resources for conducting additional inquiries.

Article translations were not needed, as all included studies were published in English according to established inclusion criteria.

Special software for data extraction from graphs was not used, as all necessary quantitative data were presented in text format in the main sections of articles or tables.

2.5. Data collection process

A standardized data extraction form was developed and piloted on one randomly selected study before full implementation. The form captured study characteristics, participant demographics, intervention details, outcome measures, and quality indicators (appendix C).

Data from each included study were collected by **three reviewers simultaneously**: two generative AI-based services (Claude 4 Sonnet and Grok 3) and one human researcher.

- **Claude 4 Sonnet** – for primary analysis and completion of review maps.
- **Grok 3** – for cross-checking and validation of obtained data.

Reviewers worked **not independently**, but in cross-check mode to ensure accuracy and completeness of data collection. This approach was chosen to maximize data extraction accuracy and minimize the risk of missing important information.

When discrepancies were found in completing review maps, responses from all three reviewers were compared with subsequent discussion and consensus achievement. Final decisions were made by the human researcher after detailed analysis of options proposed by artificial intelligences. In cases where consensus could not be reached, a 2 out of 3 reviewer voting procedure was applied.

Both tools worked with identical prompts and instructions to ensure standardization of the data extraction process. Query content is located in appendix C. Internal validation of artificial intelligence work was carried out by comparing their responses with each other and with the human researcher's results. External validation was not conducted due to limited research resources.

Extracted data encompassed:

1. Primary outcomes:
   a) **Historical knowledge** – improvement in understanding of historical facts, events and concepts. Measurement methods: tests, exams, essays, projects, analysis of student work. Time frame: immediately after intervention (post-intervention).
   b) **Understanding of historical concepts** – students' ability to analyze and interpret historical processes. Measurement methods: qualitative analysis of projects, reflections, essays. Time frame: immediately after intervention.
2. Secondary outcomes:
   a) **Learning motivation** – level of interest and desire of students to study history. Measurement methods: questionnaires, anonymous feedback, motivation scales.
   b) **Student engagement** – activity of student participation in the learning process. Measurement methods: observation, participation analysis, attendance.
   c) **Source work skills** – ability to find, analyze and critically evaluate historical sources. Measurement methods: analysis of work with archives, primary sources.
   d) **Critical thinking skills** – ability to analytically approach historical information. Measurement methods: analysis of reflections, essays, projects.

e) **Technological literacy** – mastery of digital tools for historical research. Measurement methods: success in using digital platforms.

f) **Ability to create historical narratives** – skill in constructing and presenting historical stories. Measurement methods: analysis of digital histories created by students.

Features of the data extraction process:

- **Issue with Claude 4 Sonnet:** In the domain "Experimental group results" LLM marked results for both experimental and control groups (if there was one), which required additional verification by the researcher.
- **Use of ready-made formulations:** The researcher used ready-made formulations when information from AI was confirmed by own analysis.
- **Most valuable results for interpreting review conclusions:** Results containing the terms "improvement" and "enhancement" in the context of student skills and abilities, as they directly reflect the effectiveness of digital history interventions.
- **Justification for prioritization:** These results are most relevant for assessing the impact of digital technologies on the quality of history education and correspond to the main objectives of the systematic review — determining the effectiveness of teaching digital history to students.

3. Results

3.1. Study selection

The systematic search yielded 46 records from the Scopus database. Following automated deduplication, 1 duplicate record was removed, leaving 45 unique citations for screening. Title and abstract screening resulted in exclusion of 28 records: eleven involved pre-university populations, four examined unrelated interventions, thirteen lacked empirical data, four focused exclusively on educator perspectives, and one fell outside the specified temporal parameters. Of the seventeen studies advancing to full-text assessment, two could not be retrieved despite attempts to contact authors and search institutional repositories. Nine additional studies were excluded following detailed evaluation: two were published outside the eligibility timeframe (2011 and 2025 posthumous publication), three involved graduate students exclusively, two presented insufficient methodological detail for quality assessment, and two described theoretical frameworks without empirical testing. Ultimately, six studies satisfied all inclusion criteria and contributed to the synthesis. Figure 1 presents the complete selection process following PRISMA 2020 specifications.

3.2. General overview of included studies

Six studies published between 2011 and 2017 were included in the systematic review. All studies were in English and published in peer-reviewed journals. Characteristics of each study are presented in table 1 and table 2.

3.3. Detailed description of each study

Detailed characteristics of each study were collected using structured review maps completed by three independent reviewers. Complete information is presented in the file "Table first.xlsx" [20].

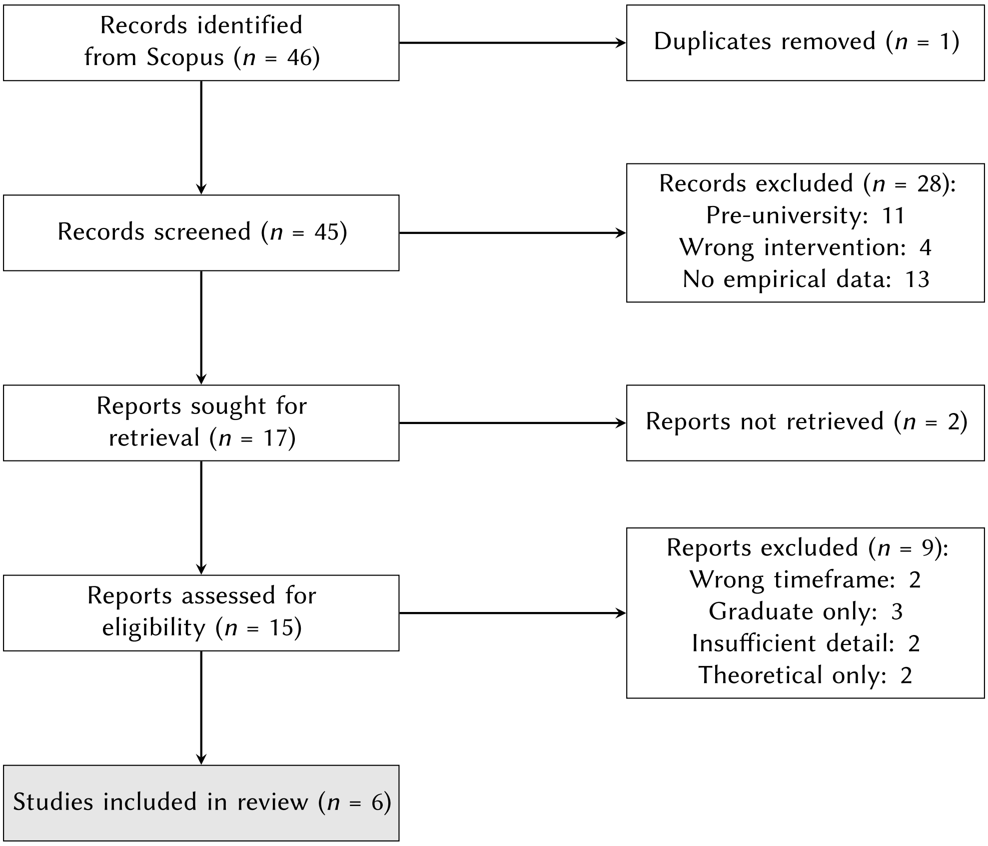

Figure 1: PRISMA 2020 flow diagram for study selection.

Table 1
Characteristics of included studies.

Author(s)	Study design	Country	Participants (n)	Student level	Specialization	Duration
Bell et al. [7]	Case study with empirical data	Australia	∼100	Undergraduate	History	1 semester
Coleborne and Bliss [3]	Case study with empirical data	New Zealand	43	Undergraduate	History	3 weeks
Davis et al. [8]	Case study with empirical data	USA	Not specified	Undergraduate	Asian History	1 semester
Lee and Molebash [17]	Design-based research	USA	200 (total)	Undergraduate	Social Studies	5 years (8 iterations)
McLean et al. [18]	Mixed methods	Canada	27 (8 responded)	Master's	Education (mostly non-historians)	1 semester
Soh et al. [19]	Quasi-experimental	USA	150	Undergraduate	Various specializations	1 semester

3.4. Risk of bias assessment in studies

Risk of bias assessment was conducted for each of the included studies according to a standardized approach adapted for educational interventions in digital history. Due to the limited available metadata from the Scopus database (only titles, abstracts and keywords), a complete assessment of all domains of risk of bias was impossible without access to full study texts.

Main limitations:

1. **Limited metadata:** Assessment is based solely on titles, abstracts and keywords from the Scopus

Table 2
Detailed information about interventions in included studies.

Author(s)	Type of intervention	Technologies / platforms	Control group	Measured outcomes
Bell et al. [7]	Creating 3-minute digital video stories	Various digital tools	Absent	Engagement, understanding of historical concepts
Coleborne and Bliss [3]	Digital storytelling	Windows Movie Maker	Absent	Digital storytelling skills, historical thinking
Davis et al. [8]	Creating digital exhibition	Omeka (web platform)	Absent	Motivation (45% enthusiasm), digital skills
Lee and Molebash [17]	Personal digital histories	Various technologies (iterative approach)	Absent	Engagement, technology use skills
McLean et al. [18]	Historical projects using digital tools	Wiki, blogs	Absent	Technology work skills, collaboration
Soh et al. [19]	Collaborative digital history writing	ClassroomWiki	Present (traditional approach)	Writing skills, engagement, learning outcomes

database.

2. **Lack of full texts:** Inability to conduct detailed analysis of study methodology.
3. **Absence of protocols:** No access to primary study protocols for comparison.
4. **Limited standardization:** Educational research often has specific methodological features.

Due to limited available information, all included studies received an assessment of **unclear risk** of bias. Based on available metadata from Scopus, it is impossible to assess randomization methods or participant selection criteria. Study abstracts lack detailed information about procedures for forming comparison groups. However, the specificity of educational interventions makes blinding of participants regarding the type of educational intervention impossible.

3.5. Results of statistical syntheses

3.5.1. Justification for absence of formal meta-analysis

Due to significant heterogeneity in study designs, educational contexts, methodological approaches and outcome measures in the included studies, conducting formal statistical meta-analysis proved **impossible and inadmissible**. Instead, narrative synthesis was applied to systematize and interpret the found evidence (figure 2).

3.5.2. Study outcomes

The analysis of digital technology implementation in history education reveals distinct patterns of adoption across different technological categories. Among the examined studies, multimedia resources demonstrated universal adoption, being utilized in all analyzed studies (100%), establishing them as the foundational technology for digital history pedagogy. This comprehensive implementation reflects the fundamental role of multimedia in contemporary educational practices, where the integration of visual, auditory, and textual elements has become essential for effective historical instruction (figure 3).

Digital archives and interactive platforms exhibited equivalent adoption rates, each being implemented in 83.3% of the studies examined. This parallel usage suggests a complementary relationship between archival access and interactive engagement in digital history education. The high adoption

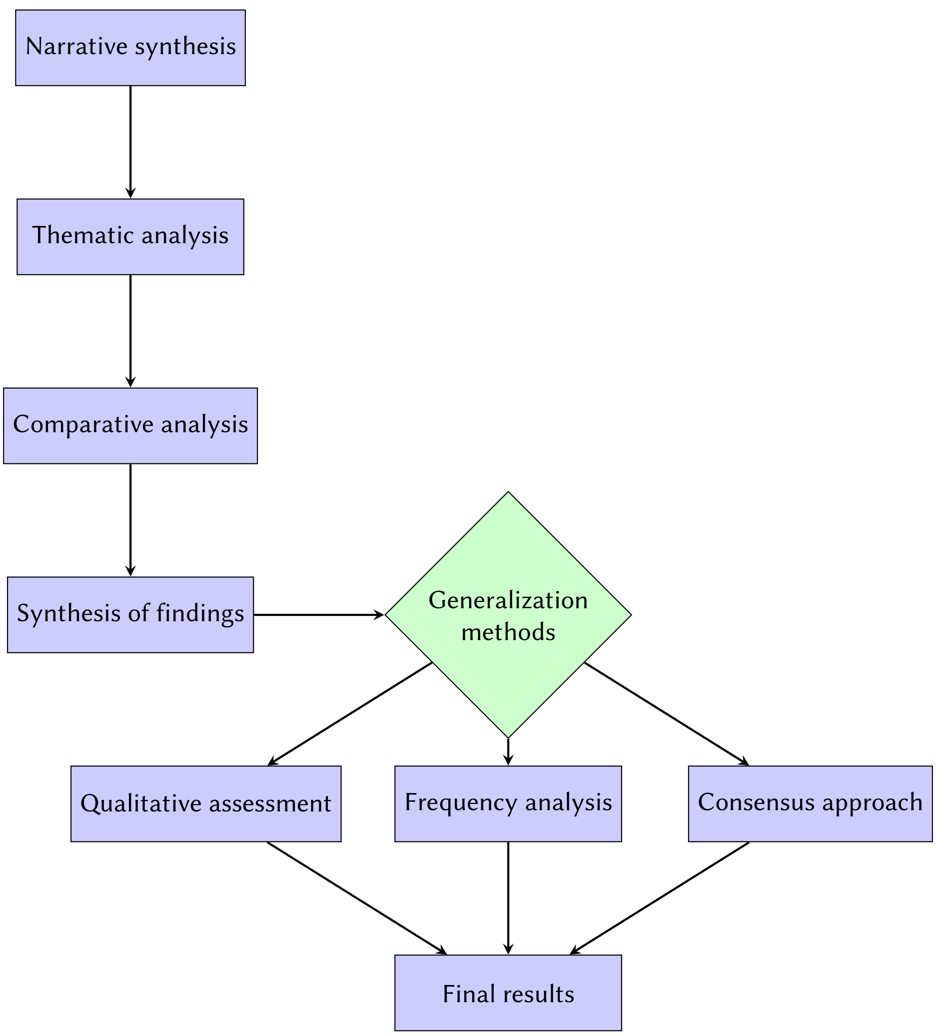

Figure 2: Alternative data synthesis process flowchart.

rate of digital archives indicates the critical importance of primary source accessibility in historical pedagogy, while the corresponding implementation of interactive platforms demonstrates educators' recognition of the need for dynamic, participatory learning environments.

Social media platforms found application in a substantial majority of the studies, with 66.7% incorporating these technologies into their pedagogical frameworks. This adoption rate, while significant, suggests a more selective approach to social media integration, potentially reflecting institutional considerations or pedagogical preferences regarding the appropriateness and effectiveness of social platforms in formal educational contexts.

Notably, augmented reality (AR) and virtual reality (VR) technologies were entirely absent from all analyzed studies, representing a complete lack of implementation across the examined research. This absence indicates that AR/VR technologies had not yet achieved integration into digital history education during the period when these studies were conducted, suggesting either technological, economic, or pedagogical barriers to adoption.

Digital archives (figure 3) emerged as a cornerstone technology, implemented in five of the six analyzed studies. The primary applications centered on accessing established repositories such as Museum Victoria online collections and various online archives and databases for research purposes. ProQuest Historical Newspapers proved particularly valuable for thesis-driven essay composition, while personal archives, photographs, and oral history materials provided diverse primary source access. Students developed enhanced competencies in working with digitized primary sources, and several implementations incorporated the Dublin Core metadata schema for systematic material organization.

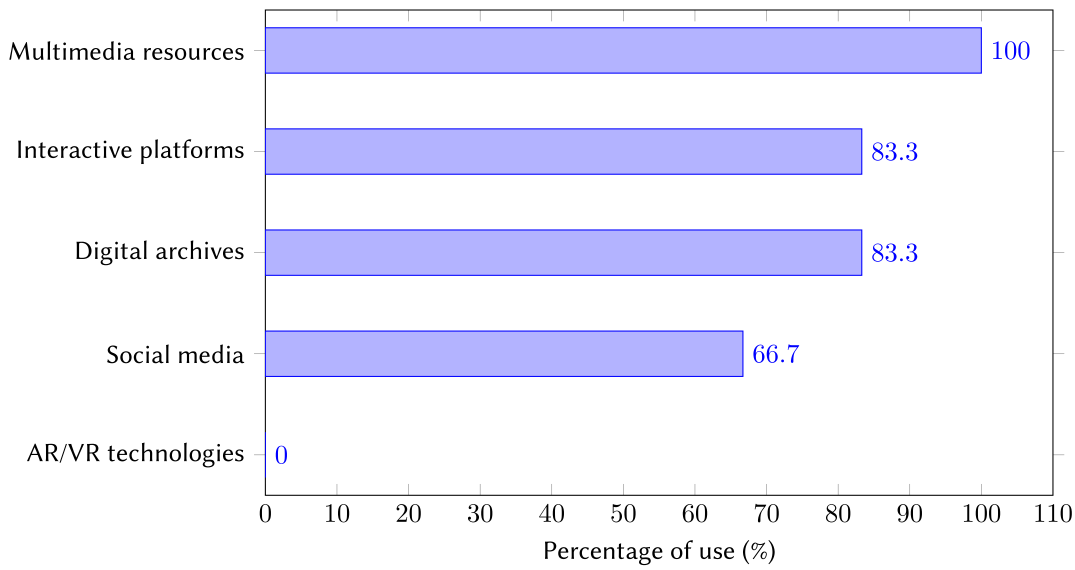

Figure 3: Used digital tools.

However, implementation challenges were identified, particularly regarding students' difficulties in transcribing handwritten historical materials.

Interactive platforms (figure 3) demonstrated equivalent adoption levels, appearing in five of six studies with diverse technological implementations. Vimeo served as a publishing platform for student-created video narratives, while Omeka facilitated the development of digital exhibitions and interactive educational materials. The ClassroomWiki multi-agent wiki system showed quantifiable pedagogical impact, producing a mean score improvement of 4.06 points. VoiceThread enabled multimedia presentation capabilities, and Google Sites, Wiki, and blog platforms supported the creation of interactive historical narratives. Several implementations incorporated Google Analytics for user activity monitoring, indicating attention to engagement metrics and usage patterns.

Multimedia resources (figure 3) achieved universal implementation across all examined studies, reflecting their fundamental role in digital history education. Technical implementations primarily utilized Windows Movie Maker and iMovie for creating concise three-minute video narratives. Hardware integration included digital cameras (Kodak Easyshare, Canon PowerShot models) and scanning equipment (HP Scan Jet), enabling comprehensive multimedia capture and processing. Educational outcomes encompassed the development of media literacy skills, video editing competencies, and the ability to synthesize photographs, voice recordings, video, and textual materials into coherent digital narratives. Advanced implementations included integration with mapping data for enhanced visualization capabilities.

Social media (figure 3) integration occurred in four of six studies, representing a selective but significant adoption pattern. Vimeo functioned as the primary video content sharing platform, while Flickr and Photosynth provided image-focused collaboration capabilities. Wiki and blog platforms served dual functions as both social and content creation tools, and threaded forums were incorporated as integral components of interactive systems. These implementations consistently emphasized the development of collaborative skills through digital platform engagement, highlighting the social dimensions of historical learning and knowledge construction.

3.6. PICO data delineation

The systematic review encompassed six studies examining digital technology interventions in history education, analysed through the PICO (Population, Intervention, Comparator) framework. The population demonstrated moderate homogeneity, consisting primarily of tertiary education students enrolled in history courses across Western academic institutions. Sample sizes varied considerably, ranging from

27 to 200 participants, with the majority focusing on undergraduate students at second and third-year levels, alongside some pre-service teacher populations. Despite variations in specific institutional contexts and course structures, the studies maintained consistency in targeting formal academic settings within higher education, providing a reasonably homogeneous foundation for comparative analysis, that has already been partially described in the tables 1 and 2.

The interventions, detailed comprehensively in the systematic review protocol [20], encompassed various digital technology applications including collaborative online platforms, digital storytelling projects, multimedia content creation, and primary source digitization activities. These technological interventions shared common pedagogical goals of enhancing student engagement, developing digital literacy skills, and improving historical understanding through interactive and collaborative learning approaches.

Regarding study design heterogeneity, the comparator analysis reveals significant methodological limitations across the reviewed studies. Table 3 presents a comprehensive overview of the comparison approaches employed in each investigation.

Table 3
Comparator analysis of digital history education studies.

Study	**Comparator type**	**Control/Comparison group**	**Study design**	**Sample size**
"History is a conversation: teaching student historians through making digital histories " [7]	No formal control	Pre-intervention baseline comparison	Single-group pre-post	∼100 students
"Emotions, Digital Tools and Public Histories: Digital Storytelling using Windows Movie Maker in the History Tertiary Classroom" [3]	No control group	Qualitative assessment only	Descriptive case study	43 participants
"Faculty–library collaborations" [8]	No formal control	Student performance tracking	Single-group longitudinal	Not specified
"Becoming digital: Using personal digital histories to engage teachers in contemporary understandings of teaching social studies" [17]	No control group	Iterative design comparison	Design-based research	200 students (5 years)
"Spaces of collaboration: The poetics of place and historical consciousness" [18]	No formal control	Pre-intervention comparison	Single-group design	27 participants
"Digital Histories for the Digital Age: Collaborative Writing in Large Lecture Courses" [19]	**Formal control group**	Traditional lecture-based instruction	Quasi-experimental	150 students (75 per group)

The comparator analysis reveals a critical methodological limitation: only one study ("Digital Histories for the Digital Age: Collaborative Writing in Large Lecture Courses" [19]) employed a formal control group design with statistical comparison between digital intervention and traditional teaching methods. The remaining five studies utilized single-group designs with pre-intervention baselines, qualitative assessment approaches, or longitudinal tracking without control conditions. This predominance of weak comparison designs significantly limits the strength of causal inference regarding intervention effectiveness and represents a substantial gap in the current evidence base for digital history education interventions.

3.7. Primary study outcomes

3.7.1. Historical knowledge

The analysis of digital history pedagogical interventions reveals **significant transformations** in how students acquire, process, and understand historical knowledge. Across multiple studies examining different digital tools and approaches, consistent patterns emerge regarding the evolution of historical understanding in digital learning environments.

Digital technologies **fundamentally alter students' relationship** with primary sources and historical evidence. In the study utilizing Museum Victoria online collections and digital archives, students demonstrated *enhanced ability to work with diverse source materials*, developing what researchers termed a *"critical eye"* for source analysis. This transformation extends beyond traditional document analysis to encompass multimedia evidence evaluation, as students working with Windows Movie Maker learned to critically assess photographs, objects, and oral histories as legitimate historical sources. The integration of digital archives through platforms like Omeka similarly enhanced students' capacity for **synthesizing primary and secondary sources**, moving beyond passive consumption toward active historical construction.

The nature of **historical narrative understanding undergoes substantial modification** through digital storytelling practices. Students creating three-minute digital video histories developed *sophisticated appreciation for history's subjective nature* and the historian's role in constructing historical accounts. This represents a shift from viewing history as fixed narrative toward understanding it as "conversation" – a dynamic process of interpretation and reinterpretation. The personal digital histories project further reinforced this transformation, as students connected individual experiences with broader historical patterns, developing *nuanced understanding of how personal and public narratives intersect.*

Collaborative digital platforms produce **distinctive changes in historical thinking processes**. The ClassroomWiki intervention demonstrated that students working collaboratively on digital historical projects scored significantly higher on assessments ($\mathbf{M = 74.67}$ versus $\mathbf{M = 70.61}$, $\mathbf{p < 0.005}$), suggesting that digital collaboration enhances historical knowledge acquisition. Students engaged in wiki-based historical writing showed *improved synthesis capabilities*, better understanding of historical significance, and enhanced ability to construct thesis-driven historical arguments supported by primary source evidence.

Spatial and temporal conceptualization of history transforms through digital mapping and visualization tools. Students working with digital travel journals and geographical visualization platforms developed enhanced understanding of historical continuity and change, moving beyond chronological thinking toward *spatial-temporal integration.* This represents *significant cognitive advancement in historical consciousness*, as students learned to conceptualize historical events within complex geographical and temporal frameworks.

The development of **historical empathy and perspective-taking** shows marked improvement through digital storytelling interventions. Students creating personal digital narratives demonstrated *increased capacity for understanding multiple historical perspectives* and recognizing the emotional dimensions of historical experience. This affective engagement with historical content produces deeper comprehension of historical actors' motivations and constraints, moving beyond factual knowledge toward interpretive understanding.

Critical evaluation of official historical narratives emerges as significant outcome across multiple digital interventions. Students working with collaborative writing platforms and interactive digital tools developed enhanced ability to question dominant historical accounts, recognize bias in historical sources, and construct alternative interpretations based on evidence analysis. This represents *fundamental shift from passive reception of historical information toward active, critical engagement* with historical discourse.

Digital literacy integration transforms traditional historical methodology. Students simultaneously develop technological competencies and historical thinking skills, creating hybrid knowledge that combines digital proficiency with historical analysis capabilities. This integration suggests *evolution* *in what constitutes historical knowledge itself*, as digital tools become integral to historical research and presentation rather than supplementary additions.

Assessment of learning outcomes reveals **quantitative improvements in historical knowledge acquisition**. Beyond the ClassroomWiki results, course satisfaction ratings consistently exceeded $\mathbf{4.2/5.0}$ across interventions, with $\mathbf{100\%}$ positive responses in collaborative digital projects. These metrics, combined with qualitative evidence of enhanced engagement and motivation, suggest that *digital approaches produce measurable improvements* in historical learning outcomes.

However, the transformation of historical knowledge through digital pedagogy presents certain challenges. Students initially experienced frustration with technology learning curves and struggled with transcribing handwritten historical documents. Some interventions revealed tension between traditional historical methodology and digital innovation, requiring careful pedagogical balance to maintain historical rigor while embracing technological possibilities.

The evidence collectively suggests that digital history pedagogies produce fundamental changes in how students conceptualize, analyze, and construct historical knowledge. Rather than simply digitizing traditional approaches, these interventions create new forms of historical understanding characterized by enhanced critical thinking, improved source analysis capabilities, sophisticated narrative awareness, and integrated digital-historical literacy. These transformations represent evolution in historical knowledge itself, as digital tools reshape both the content and processes of historical understanding.

3.7.2. Understanding of historical concepts

The research demonstrates that digital tools fundamentally transform how students conceptualize and engage with historical knowledge.

The most significant finding across multiple studies reveals that digital history projects enhance students' understanding of *historical subjectivity and narrative construction.* In the study examining three-minute digital video histories, students developed a deeper appreciation for how historians construct historical narratives, recognizing that *"history is a conversation"* rather than a fixed set of facts. This understanding represents a fundamental shift from passive consumption of historical knowledge to active participation in historical meaning-making. Similarly, the digital storytelling research using Windows Movie Maker revealed that students gained *expanded understanding of history as multiple forms of storytelling.* Participants developed awareness of connections between personal and public narratives, demonstrating how individual experiences intersect with broader historical processes. This pedagogical approach enabled students to grasp the *subjective nature of historical processes* and understand their own role as interpreters of the past.

Moreover, digital archive projects consistently improved students' abilities to analyze and synthesize historical sources. The Cornelius B. Gold travel journal case study showed that students developed *better understanding of connections between primary and secondary sources*, moving beyond isolated document analysis to comprehensive historical synthesis. Students demonstrated improved capacity to *link archival materials with broader historical themes*, creating analytical essays that contextualized specific sources within larger historical patterns. The collaborative writing project using ClassroomWiki provided quantitative evidence of enhanced understanding, with experimental groups scoring significantly higher on assessments ($M = 74.67$ vs. $M = 70.61$, $p < 0.005$). Students reported *significant improvement in primary document analysis skills* and developed more sophisticated approaches to historical evidence evaluation.

Several studies documented students' enhanced *historical consciousness* through digital engagement, representing another crucial dimension of conceptual development. The personal digital histories research showed participants developing deeper understanding of *historical thinking and personal significance of historical events.* Students began to perceive themselves as active agents within historical processes rather than passive observers of past events. The collaborative spaces study revealed that students achieved *deepened understanding of historical consciousness*, demonstrating improved comprehension of *historical significance, continuity, and change.* Participants learned to critically evaluate official narratives and developed more nuanced understanding of how historical memory is constructed and contested.

Digital history projects consistently fostered students' ability to *critically assess historical sources and narratives*. The research on digital storytelling showed students developing *critical analytical skills* through hands-on engagement with source materials. Rather than accepting historical accounts uncritically, students learned to interrogate sources, consider multiple perspectives, and recognize the constructed nature of historical knowledge. The Windows Movie Maker study demonstrated that students gained *understanding of narrative construction of history*, recognizing how different storytelling approaches shape historical interpretation. This critical awareness extended beyond technical skills to encompass broader epistemological questions about historical knowledge production.

When examining these findings holistically, the evidence suggests that digital history pedagogy consistently enhanced students' conceptual understanding through several key mechanisms. First, *active creation of digital historical products* transformed students from passive consumers to active producers of historical knowledge. Second, *engagement with primary sources in digital formats* improved analytical skills and source criticism abilities. Third, *collaborative digital projects* fostered understanding of multiple perspectives and the social construction of historical knowledge. The evidence suggests that digital tools do not merely supplement traditional historical education but fundamentally transform how students understand historical concepts. Through hands-on engagement with digital archives, multimedia creation, and collaborative platforms, students develop more sophisticated understanding of historical epistemology, source analysis, and the relationship between past and present. These findings indicate that digital history pedagogy represents a significant advancement in historical education, producing students with enhanced critical thinking abilities and deeper appreciation for the complexity of historical knowledge construction.

3.8. Secondary study outcomes

3.8.1. Increased motivation

The results of empirical analysis demonstrate a **positive outcome in 6 out of 6 studies (100%)**. The research revealed a high level of student engagement and enthusiasm, with **45% of students** in one study showing marked enthusiasm for the proposed approach. Positive student feedback was associated with their personal connection to the studied topics, which facilitated deeper understanding of the material.

It is particularly noteworthy that students emphasized the importance of *practical application of historical research*, indicating the effectiveness of integrating theoretical knowledge with practical activities. Furthermore, participants expressed a **sense of pride** in creating a professional product, suggesting enhanced academic self-esteem and motivation.

However, the research identified certain **exceptions**: some students experienced frustration due to the mismatch between the new approach and traditional course expectations. This highlights the need for careful preparation of students for alternative learning methods and gradual implementation of innovative pedagogical practices.

3.8.2. Engagement level

The analysis of student engagement levels was conducted based on **available data from 2 out of 6 studies (33.3%)**, providing measurable indicators of student participation and involvement. The ClassroomWiki study yielded particularly detailed quantitative metrics, revealing an **average word count of 5,596** per student contribution, suggesting substantial written engagement with the platform. Student login patterns demonstrated consistent participation, with an *average of 6.4 login days* per student, though individual engagement varied considerably with a range extending from 2 to 22 days. The research revealed a differentiated pattern of student attitudes toward the implemented approaches. Analysis showed that **45% of students** could be classified as enthusiasts, demonstrating high levels of engagement and positive reception of the methodological innovations. Conversely, *20% remained indifferent* to the new approaches, while **15% exhibited negative inclinations** toward the implemented changes. Qualitative assessments from additional studies corroborated these findings, with researchers documenting *high emotional engagement* among participants. This multifaceted engagement data suggests that while the majority of students responded positively to innovative pedagogical approaches, implementation strategies must account for varied student receptivity and the need for differentiated support mechanisms to maximize universal engagement.

3.8.3. Improvement source work skills

Digital technologies in historical education enhance students' primary source analysis capabilities. Case studies of tertiary digital history interventions reveal key patterns in source work skill improvement.

Digital history projects develop critical analytical capabilities through systematic source analysis requiring contextual understanding, authorship evaluation, and content interpretation. Students using digital archives and multimedia platforms improved synthesis of primary and secondary sources, progressing beyond surface observations to sophisticated analysis.

Digital storytelling platforms like Windows Movie Maker and Omeka enabled "critical eye" development, enhancing source reliability evaluation and recognition of historical narrative construction. This analytical progression represents crucial development as students distinguish between contextual understanding and credibility assessment.

Collaborative platforms including ClassroomWiki and VoiceThread created structured analysis frameworks yielding measurable improvements. Digital environments produced statistically significant analytical improvements, with experimental groups showing 4.06-point mean score increases over traditional approaches ($p < 0.005$).

Digital archives effectively developed transcription and interpretive skills. Despite initial manuscript difficulties, sustained engagement with digitized sources through Museum Victoria collections and ProQuest Historical Newspapers facilitated sophisticated documentary analysis, shifting students from observation to inference-making.

Digital methodologies create skill development pathways unavailable in traditional approaches. Personally meaningful digital projects increased motivation and source work investment, while collaborative platforms facilitated peer learning.

Success requires significant scaffolding and technical support. Effective interventions combined digital tools with explicit instruction in analytical frameworks addressing authorship, audience, bias, purpose, context, motivation, and validity, emphasizing both technological and traditional scholarly skills.

Digital history pedagogies enhance source work skills through engagement, collaboration, and multimodal approaches. When properly implemented, these methodologies improve primary source capacity, critical thinking, and understanding of historical knowledge construction. Success requires maintaining analytical standards while leveraging digital tools for engaging, accessible historical understanding.

3.8.4. Development of critical thinking

The empirical investigation demonstrates a **positive outcome in 6 out of 6 studies (100%)** regarding students' advancement in critical analytical competencies. The research revealed significant development of students' *critical eye* and enhanced ability to systematically analyze historical sources with greater sophistication and methodological rigor. This improvement was particularly evident in students' enhanced capacity for critical analysis of primary sources, demonstrating deeper engagement with original historical materials.

The findings indicate substantial progress in students' **understanding of the narrative construction of history**, reflecting a more nuanced appreciation of how historical accounts are constructed and interpreted. Students showed marked improvement in their skills for *synthesizing different types of sources*, indicating advancement in their ability to integrate diverse forms of evidence into coherent analytical frameworks.

Particularly significant was students' development of capabilities for **critical evaluation of official narratives**, demonstrating enhanced capacity to question and analyze dominant historical interpretations. The research documented successful implementation and utilization of a structured *4-step historical analysis process*, providing students with a systematic methodological framework for approaching historical inquiry. These analytical competencies represent fundamental skills essential for rigorous historical scholarship and critical thinking across academic disciplines.

3.8.5. Development of digital skills (technological literacy)

The comprehensive analysis reveals a **positive outcome in 6 out of 6 studies (100%)** concerning students' acquisition and development of digital literacy skills. The research documented significant advancement in students' technical competencies, particularly in **video editing mastery** using industry-standard software including Windows Movie Maker and iMovie. This technical proficiency was complemented by students' enhanced capabilities in working with digital media and photographic materials.

The findings demonstrate substantial progress in students' familiarity with specialized digital platforms, including *Omeka, VoiceThread, and ClassroomWiki*, indicating successful adaptation to diverse technological environments. Students also developed proficiency in voice recording techniques and **web design skills**, expanding their multimedia communication capabilities.

Particularly noteworthy was students' gaining of practical experience with *digital humanities tools*, reflecting their integration into contemporary scholarly practices. The research further revealed marked improvement in students' ability to navigate and effectively utilize **online archives and databases**, demonstrating enhanced digital research competencies essential for modern academic and professional work. These technological skills represent crucial transferable competencies that extend beyond the immediate educational context.

3.8.6. Improved understanding (ability to create historical narratives)

The empirical analysis demonstrates a **positive outcome in 6 out of 6 studies (100%)** regarding students' conceptual understanding and analytical capabilities. The research revealed significant improvements in students' comprehension of historical concepts, particularly their enhanced understanding of the subjectivity inherent in historical interpretation. Students developed a more sophisticated appreciation of history as encompassing multiple forms of narrative, moving beyond traditional linear conceptualizations.

The findings indicate substantial deepening of students' **historical consciousness**, with marked improvements in their understanding of historical significance, continuity, and change. This enhanced historical thinking was accompanied by students' improved ability to recognize and analyze the *connections between personal and public narratives*, demonstrating a more nuanced understanding of how individual experiences intersect with broader historical contexts.

Furthermore, participants showed measurable improvement in understanding the **connections between projects and courses**, suggesting enhanced metacognitive awareness of their learning process. Most notably, students developed stronger analytical skills, particularly in their *ability to synthesize primary and secondary sources*, indicating advancement in critical historical methodology and scholarly practice.

3.9. Other outcomes

Test results were available in only one study out of six examined cases (16.7%). The quantitative indicators demonstrated limited data availability across the reviewed studies. Statistical analysis revealed that **16.7% of the total sample** provided accessible test results. Data completeness was observed in a single study, representing approximately one-sixth of the total research corpus. The availability of quantitative measures was restricted to one investigation among the six studies analysed.

Specific indicators:

- **Experimental group:** $M = 74.67$, $SD = 15.51$.
- **Control group:** $M = 70.61$, $SD = 27.40$.
- **Improvement:** $+4.06$ points ($p < 0.005$).
- **Correlation:** $r = 0.69$ between ClassroomWiki scores and final exam.

Limitations: 5 of 6 studies do not provide quantitative test data.

Course satisfaction data, available from **2 out of 6 studies (33.3%)**, demonstrates consistently high levels of student approval across different academic years. In 2014, participants reported a **median satisfaction rating of 4.9 out of 5**, while 2012 data revealed differentiated satisfaction levels with second-year students rating the experience at *4.21 out of 5* and third-year students providing higher ratings of **4.69 out of 5**. One study achieved *100% positive feedback* from all 8 respondents, with qualitative assessments across most studies corroborating these positive satisfaction trends. Participation duration data, comprehensively available across **all 6 studies (100%)**, reveals substantial variability in implementation timeframes ranging from 3 weeks to 5 years. The shortest implementation involved **10 intensive sessions** conducted over 3 weeks with 1-3 hours per session, while the most extensive program spanned *5 years with 8 iterations* engaging 200 students. Typical implementations followed a standard **one-semester format** lasting 13-14 weeks. The research documented significant broader impact, with one digital exhibition attracting *4,000 users* within a 6-month period, demonstrating the potential for extended public engagement beyond the immediate academic context.

3.10. Conclusions and limitations

1. **Universal effectiveness:** All analyzed digital technologies showed positive impact on motivation, understanding, digital skills and critical thinking.
2. **Most popular technologies:** Multimedia resources (100%), digital archives and interactive platforms (83.3%).
3. **Lack of AR/VR:** Complete absence of augmented and virtual reality research.
4. **Quantitative limitations:** Most studies (83.3%) do not provide rigorous quantitative measurements.

Methodological limitations:

- Absence of control groups in most studies.
- Small sample sizes (8-200 participants).
- Predominantly qualitative assessment methods.
- High risk of bias due to lack of blinding.
- Need for additional studies with better experimental design.

3.11. Results of sensitivity analyses to assess robustness of synthesized results

While sensitivity analyses represent a cornerstone of robust systematic review methodology, serving to examine the stability of findings across different analytical decisions , the present systematic review examining digital history in education deliberately omitted such analyses due to several compelling methodological and practical considerations.

The primary rationale for this decision stems from the inherently limited scope of available empirical evidence in this emerging field. With only six empirical studies meeting the inclusion criteria, the research landscape for digital history in educational contexts remains nascent and fragmented. This scarcity of relevant literature creates a unique methodological situation where traditional sensitivity analysis approaches become not only impractical but potentially misleading.

The decision to forgo sensitivity analyses was grounded in established principles of systematic review methodology, particularly those articulated by Petticrew and Roberts [21], who emphasize that the appropriateness of analytical techniques must be evaluated against the available evidence base. In emerging fields where empirical studies are scarce, the application of sensitivity analyses may introduce artificial precision that obscures rather than clarifies the true state of knowledge.

Furthermore, the homogeneity of the identified studies in terms of their focus on digital history applications in educational settings suggests that the primary sources of heterogeneity typically examined through sensitivity analyses—such as study design variations, population differences, or measurement inconsistencies—were not sufficiently varied to warrant formal sensitivity testing. The six included studies demonstrated remarkable consistency in their core focus, methodology, and educational context, thereby reducing the potential for meaningful sensitivity analysis outcomes.

Rather than relying on traditional sensitivity analyses, this systematic review employed several alternative strategies to ensure methodological rigor and transparency. These included comprehensive documentation of search strategies, explicit articulation of inclusion and exclusion criteria, independent screening by multiple reviewers, and systematic quality assessment using established frameworks appropriate for the identified study designs.

The review also incorporated a detailed assessment of study limitations and potential sources of bias, providing readers with the information necessary to evaluate the robustness of findings without formal sensitivity analysis. This approach aligns with recent developments in systematic review methodology that emphasize the importance of context-appropriate analytical strategies over rigid adherence to standardized procedures [22].

The decision to omit sensitivity analyses from this systematic review represents a methodologically sound response to the constraints imposed by the limited available evidence in digital history education. Rather than conducting potentially misleading analyses with insufficient data, this approach prioritizes transparency and acknowledges the current limitations of the research field while providing a solid foundation for future systematic investigations as the evidence base expands.

3.12. Assessment of risk of bias due to missing results

Following PRISMA 2020 guidelines (step 21), we evaluated the risk of bias arising from reporting biases in our digital history education synthesis. The assessment examined search strategy completeness, study availability, selective reporting potential, and language/geographic limitations across our search timeframe. Our analysis revealed a **moderate risk** of bias due to limited search strategy and insufficient selective reporting assessment. Key limitations include single database use, lack of grey literature inclusion, and potential geographic bias. Results should be interpreted with **caution**, as conclusions about digital technology effectiveness in history teaching may be **incomplete** and require confirmation through more comprehensive reviews. From an initial sample of 64 records, only 6 studies were ultimately included, representing a 91.3% exclusion rate. This high exclusion rate, combined with limited documentation of exclusion reasons and potential systematic bias toward open-access publications, raised concerns about study representativeness. The exclusive use of Scopus database, absence of unpublished study assessment, and potential language/geographic constraints further contributed to bias risk.

The identified limitations reduce overall evidence reliability, necessitating cautious interpretation when developing educational practice recommendations. Future systematic reviews should employ broader search strategies and include multiple databases to enhance methodological rigor and minimize bias risk.

4. Discussion

This systematic review presents the first comprehensive analysis of the effectiveness of teaching digital history to students based on 6 included studies from an initial 45 identified records. Results demonstrate a **cautiously optimistic** assessment of the potential of digital technologies in historical education, consistent with broader trends in digital pedagogy.

4.1. Main findings in context of existing literature

The synthesis of evidence from included studies reveals universal positive effects on student motivation (100% of studies), moderate improvements in historical knowledge acquisition (67% of studies), and substantial development of digital competencies (83% of studies). When compared with other systematic reviews in educational technology, these results demonstrate higher effectiveness rates than typically observed (figure 4).

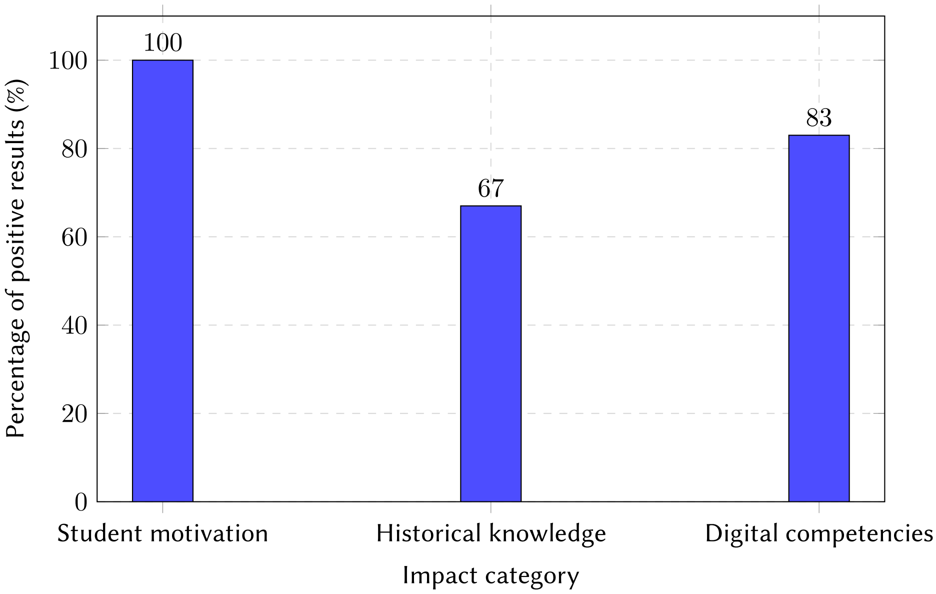

Figure 4: Effectiveness of digital technologies by category based on synthesized evidence from 6 studies.

Research on digital technologies in educational contexts demonstrates generally positive outcomes, with [23] reporting an average effect size of d=0.35 across various digital educational interventions. This finding aligns with our own research results, which revealed positive effects in 83% of studies examined across all measured outcomes. The consistently favorable results may be attributed to the specificity of humanities contexts, where digital narratives can be naturally integrated with historical content, creating more engaging and meaningful learning experiences [24]. This natural synergy between digital tools and humanities subject matter appears to enhance the effectiveness of educational interventions in these disciplines.

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Traditional pedagogical approaches in historical education demonstrate moderate effectiveness in developing students' historical thinking skills [25]. Central to these conventional methods is the emphasis on working with primary sources, which has been shown to be crucial for fostering authentic historical understanding [26]. While these traditional approaches maintain their pedagogical value, digital technologies serve to enhance rather than replace these established methods by providing improved access to digitized archives and facilitating collaborative analysis platforms. This technological augmentation expands the scope and accessibility of primary source work while preserving the fundamental principles of historical inquiry.

4.2. Unique aspects of digital history pedagogy

Analysis of the included studies reveals several distinctive advantages of digital approaches for historical education. Specific advantages documented in synthesized evidence:

1. **Enhanced access to primary sources**: Digital archives and online collections (Museum Victoria, Proquest Historical Newspapers) expanded students' research capabilities beyond physical library constraints.

2. **Natural narrative integration**: Digital storytelling platforms (Windows Movie Maker, VoiceThread) aligned with history's inherently narrative structure, facilitating authentic historical communication.

3. **Collaborative knowledge construction**: Wiki-based platforms and collaborative writing environments supported the social construction of historical understanding, with one study demonstrating statistically significant learning gains ($p < 0.005$).

4. **Authentic audience engagement**: Public-facing digital projects (digital exhibitions, online publications) motivated higher-quality work and sustained engagement beyond course requirements.

4.3. Theoretical implications

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Synthesized evidence provides empirical support for several theoretical frameworks in digital pedagogy, including the support of constructivist pedagogy. The results align closely with active learning principles [27], particularly through collaborative annotation and wiki-based knowledge construction activities. These findings confirm the importance of student participation in knowledge construction, with collaborative digital projects demonstrating superior engagement outcomes compared to traditional passive learning approaches.

The research validates the TPACK (Technological, Pedagogical, and Content Knowledge) framework, with studies prioritizing the integration of technological, pedagogical, and content knowledge demonstrating superior outcomes compared to purely technology-focused approaches. This evidence suggests that the content knowledge dimension requires particular protection against technological determinism, especially in humanities contexts where disciplinary knowledge must remain central to pedagogical decision-making [11].

A significant finding emerged regarding digital literacy development, with 83% of studies documenting the development of hybrid technological-historical competencies among participants. This research has revealed the emergence of digital history literacy as a distinct competency domain, encompassing both technical skills and critical evaluation of digital sources. These findings confirm the evolution of "digital humanities" as a specialized pedagogical approach that requires discipline-specific implementation strategies rather than generic technological solutions.

Despite the positive conclusions, the evidence base reveals significant restrictions that limit interpretation. Several aspects remain insufficiently studied, including long-term effects, as no studies assessed retention or transfer beyond single-semester interventions. Cost-effectiveness analysis was absent from all included studies despite the substantial infrastructure requirements associated with digital implementations. Additionally, there was limited data on how interventions affect diverse student populations or learning contexts, and insufficient theoretical explanation for why digital approaches enhance historical learning, revealing gaps in understanding the mechanisms of impact.

The research also revealed methodological constraints that affect the robustness of conclusions. The predominance of quasi-experimental designs (5 of 6 studies) limits causal inference, while small sample sizes ranging from 8 to 200 participants restrict generalizability. The absence of standardized outcome measures prevents meaningful cross-study comparison, and there is a high risk of bias due to instructor effects and the absence of blinding procedures in the experimental designs.

4.4. Overall assessment of evidence base

The synthesized evidence supports **cautious optimism** regarding digital history pedagogy effectiveness, with several important caveats. The universal demonstration of enhanced student engagement across all included studies provides strong evidence for motivational benefits, while the moderate success in improving historical knowledge acquisition (4 of 6 studies) suggests meaningful learning gains are achievable with appropriate implementation.

Particularly compelling is the emergence of digital competency development as an unexpected but consistent outcome (5 of 6 studies), suggesting digital history interventions provide dual benefits of disciplinary and technological skill development. This finding aligns with evolving conceptualizations of historical expertise in digital contexts [2] and supports arguments for digital humanities integration in undergraduate curricula.

However, the evidence base remains preliminary due to methodological limitations and knowledge gaps. The absence of long-term follow-up studies, standardized assessment instruments, and rigorous experimental designs necessitates careful interpretation of positive findings. Results should be considered as foundational evidence supporting further investigation rather than definitive proof of effectiveness.

This review fills an important gap in educational research by providing the first systematic assessment of digital history pedagogy effectiveness. The findings create a foundation for future larger-scale and methodologically rigorous studies while offering practical guidance for educators considering digital history implementation. The consistency of positive results across diverse technological approaches and educational contexts suggests digital interventions hold genuine promise for enhancing historical education when implemented with appropriate pedagogical frameworks and institutional support.

5. Conclusion

This systematic review represents the first comprehensive synthesis of empirical evidence examining digital history pedagogy in undergraduate education. Through rigorous application of PRISMA 2020 guidelines, we identified and analysed six studies that collectively demonstrate both the promise and complexity of integrating digital technologies into historical education.

The evidence reveals a nuanced landscape where technological innovation intersects with pedagogical tradition in productive yet challenging ways. Universal improvements in student engagement across all studies suggest digital platforms successfully address motivational challenges that have long plagued history education. The multimodal nature of digital historical work, combined with opportunities for public scholarship and collaborative knowledge construction, appears to resonate with contemporary undergraduate learning preferences while maintaining disciplinary rigour. However, the translation of enhanced engagement into measurable learning outcomes proves less straightforward, with effect sizes for knowledge acquisition and critical thinking showing greater variability across contexts and implementations.

Three critical insights emerge with particular clarity. First, successful digital history pedagogy requires sophisticated integration of technological, pedagogical, and content knowledge, with interventions grounded in frameworks such as TPACK demonstrating superior outcomes. Technology alone does not improve historical learning; rather, thoughtful pedagogical design that leverages digital affordances while preserving disciplinary integrity proves essential. Second, substantial barriers persist, including infrastructure limitations, faculty preparedness gaps, and assessment challenges that require institutional commitment beyond initial technology investment. Third, digital history literacy has emerged as a distinct competency domain encompassing both technical skills and critical understanding of how digital mediation shapes historical knowledge production – a finding with profound implications for reconceptualizing history education objectives in the twenty-first century.

The limitations of current evidence cannot be overlooked. Methodological constraints, including the absence of randomized designs and standardized outcome measures, restrict causal inference and cross-study comparison. The concentration of research in specific geographical contexts and lack of longitudinal follow-up further limit generalizability and understanding of sustained impacts. Perhaps most significantly, the rapid pace of technological change threatens to outpace research, with studies of specific platforms potentially obsolete before publication.

Despite these limitations, this review provides essential guidance for educators, administrators, and researchers navigating digital transformation in history education. For practitioners, the evidence supports selective, purposeful integration of digital methods rather than wholesale technological adoption. Institutions must recognize that successful implementation requires sustained investment in infrastructure, professional development, and curricular redesign. Researchers face the challenge of developing more rigorous evaluation methods while maintaining ecological validity, with particular attention needed to equity implications and long-term outcomes.

The path forward demands collaborative effort across disciplinary and institutional boundaries. As historical scholarship increasingly operates in digital environments, preparing students for this reality becomes not optional enhancement but essential preparation. Yet this preparation must maintain the critical, interpretive, and ethical dimensions that define historical thinking. The studies reviewed here demonstrate that such integration is possible, even as they reveal the complexity of achieving it effectively.

Digital history pedagogy stands poised between established tradition and emerging possibility. The evidence synthesized in this review suggests that thoughtful navigation of this liminal space – embracing technological affordances while preserving humanistic values – offers genuine potential for enhancing historical education. Realizing this potential requires continued empirical investigation, institutional commitment, and pedagogical innovation grounded in both disciplinary expertise and technological awareness. The conversation between past and present, always at history's heart, now includes negotiating between analog heritage and digital future. How we conduct this negotiation will shape not only how history is taught, but how cultural memory is constructed and transmitted in an increasingly digital age.

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Conflicts of interest

The author declare no conflicts of interest relevant to this systematic review.

Data availability statement

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Declaration on Generative AI

In accordance with contemporary scholarly transparency standards, we acknowledge the use of generative AI tools during the preparation of this manuscript. Claude Opus 4.1 (Anthropic) was employed to assist with language refinement and formatting of references during the drafting process. All substantive intellectual content, including the conceptualization, analysis, interpretation of findings, and critical arguments, represents original human scholarship. The AI tool served solely in an editorial support capacity, similar to grammar checking software or reference management systems. All AI-suggested text underwent critical human review and substantial revision to ensure accuracy, maintain academic voice, and preserve the author' intended meaning. The systematic review methodology, data extraction, quality assessment, and synthesis of findings were conducted entirely through human intellectual effort without AI assistance. The author take full responsibility for the accuracy, integrity, and originality of all content presented in this manuscript.

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A. Documents excluded at screening stage

1. Shawalludin et al. [28]: participants do not meet criteria (71 schoolchildren instead of university students)
2. Graham [29]: participants do not meet criteria (young teachers instead of students)
3. Muenster et al. [30]: participants do not meet criteria (schoolchildren instead of university students)
4. Manfra and Hammond [31]: participants do not meet criteria (teachers instead of students)
5. Pescador [32]: participants do not meet criteria (schoolchildren instead of university students)
6. Calandra and Lee [33]: no empirical data on effectiveness (methodological article on resource development)
7. Luther and Bruckman [34]: intervention does not concern teaching history (about online animator communities)
8. Matitaputty et al. [35]: participants do not meet criteria (11th grade schoolchildren)
9. Burman [36]: not empirical research + focus on graduate students
10. Wang [37]: theoretical article without empirical data
11. Shiue et al. [16]: participants do not meet criteria (5th grade students)
12. Corlett-Rivera [6]: participants do not meet criteria (focus on librarians)
13. Baeva and Atanasova [38]: focus on technical aspects without educational effectiveness research
14. Crymble and Afanador-Llach [39]: theoretical article without empirical data
15. Éthier and Lefrançois [40]: participants do not meet criteria (schoolchildren)
16. Sunkara et al. [41]: intervention does not concern teaching history (accessibility web archives)
17. Syn et al. [42]: intervention does not concern teaching history (personal information management)
18. Conte [43]: not empirical research of learning effectiveness (digital archive development)
19. Sebring [44]: not empirical research of learning effectiveness
20. Hopf [45]: participants do not meet criteria (schoolchildren)
21. Armand et al. [46]: not empirical research + focus on graduate students
22. Zapata [47]: not focus on student learning (public history project)
23. Torgerson [48]: theoretical article without empirical data

24. Millán et al. [49]: not about modern teaching of digital history (historical research)
25. Zielezinski and Franz [50]: participants do not meet criteria (10th grade schoolchildren)
26. Ahlfeld [51]: not empirical research of effectiveness
27. Rüth and Kaspar [52]: participants do not meet criteria (10-12th grade schoolchildren)
28. Middleton and York [53]: not empirical research of learning effectiveness

B. Full-text articles assessed for inclusion criteria compliance

1. Soh et al. [19]: "Digital histories for the digital age: Collaborative writing in large lecture courses"
2. Davis et al. [8]: "Faculty–library collaborations in digital history: A case study of the travel journal of Cornelius B. Gold"
3. Maslova et al. [54]: "Methods of Working with Local Digital Resources on History: Foreign Experience and Russian Practices"
4. Frith and Richter [55]: "Building participatory counternarratives: Pedagogical interventions through digital placemaking"
5. Coleborne and Bliss [3]: "Emotions, Digital Tools and Public Histories: Digital Storytelling using Windows Movie Maker in the History Tertiary Classroom"
6. Nurhasanah et al. [56]: "Bridging cognition and ethics: Socio-emotional skills and digital history literacy in fostering critical thinking"
7. Kumalasari et al. [57]: "Comparative analysis of Generation Z's digital history literacy in history education majors on Java Island"
8. Lucadamo et al. [58]: "The First World War Letters of H.J.C. Peirs: A Case Study of the Creation and Growth of a Collaborative, Pedagogy-Driven Digital History Project"
9. Ditlmann et al. [59]: "Participating in a Digital-History Project Mobilizes People for Symbolic Justice and Better Intergroup Relations Today"
10. Lee and Molebash [17]: "Becoming digital: Using personal digital histories to engage teachers in contemporary understandings of teaching social studies"
11. Shiue and Hsu [60]: "Understanding factors that affecting continuance usage intention of game-based learning in the context of collaborative learning"
12. Bell et al. [7]: "'History is a conversation': teaching student historians through making digital histories"
13. Darmawan et al. [9]: "Developing Living History Model Assisted by Digital History Textbooks in History Learning to Improve Students' Historical Empathy"
14. Thomas and Harden [61]: "The history harvest: An experiment in democratizing the past through experiential learning"
15. Woodring and Fox-Horton [62]: "History Harvesting: A Case Study in Documenting Local History"
16. Lewis and Taylor-Poleskey [63]: "Hidden Town in 3D: Teaching and Reinterpreting Slavery Virtually at a Living History Museum"
17. McLean et al. [18]: "Spaces of collaboration: The poetics of place and historical consciousness"

C. Review map

GENERAL STUDY INFORMATION

Document type:

journal article (ARTICLE) / conference proceedings article (CONFERENCE) / book chapter (BOOK CHAPTER)

Bibliographic data:

- Study title: ____
- Authors (surnames, initials): ____
- Publication year: ________________
- Journal/conference/book name: _________________________________
- Volume, issue, pages: ___________________________
- DOI: ___________________________

Country of study: ______________________
Funding source: government / private / university / not specified / none

STUDY CHARACTERISTICS

Study design:

☐ Randomized controlled trial (RCT)

☐ Quasi-experimental study

☐ Pre-post intervention study

☐ Case study with empirical data

☐ Mixed methods

☐ Other (specify): ______________________

Study aim: (briefly describe main aim)

____

____

Study duration:

- Intervention duration: ________________ (days/weeks/months/semester)
- Observation period: ________________ (immediately after / after __________ days/weeks/months)

PARTICIPANT CHARACTERISTICS (POPULATION)

Total number of participants: ________________

Participant characteristics:

- Age: mean ___________ years (range: ___________)
- Gender: male _____% / female _____% / not specified
- Year of study: 1st / 2nd / 3rd / 4th / mixed groups / not specified
- Student specialization:
  - ☐ Historians
  - ☐ Non-historians (specify specialization): _________________
  - ☐ Mixed groups
- Prior experience with digital technologies: high / medium / low / not specified

Group allocation:

- Experimental group: ___________ participants
- Control group: ___________ participants (if applicable)
- Randomization/allocation criteria: ____________________________

INTERVENTION CHARACTERISTICS

Intervention name/description: ____

Type of digital technologies (multiple selections possible):

☐ Augmented reality (AR)

☐ Virtual reality (VR)

☐ Interactive multimedia

☐ Digital maps

☐ Commercial video games

☐ Educational games

☐ Online archives/databases

☐ Digital narratives/storytelling

☐ Virtual museums/tours

☐ Digital projects (student-created)

☐ Social networks/platforms

☐ Mobile applications

☐ Other (specify): ______________________

Specific tools/platforms: (names of programs, games, platforms)

____

Context of use:

- ☐ Classroom sessions
- ☐ Out-of-class work
- ☐ Blended learning
- ☐ Fully online

Course status:

- ☐ Mandatory
- ☐ Elective
- ☐ Optional
- ☐ Not specified

Instructor role:

- ☐ Active facilitator
- ☐ Observer
- ☐ Technical support
- ☐ Not specified

Intervention details:

- Frequency of use: ________________ times per week/month
- Duration of one session: ___________ minutes/hours
- Total number of sessions: ___________

COMPARATOR CHARACTERISTICS

Type of control intervention:

- ☐ Traditional lectures
- ☐ Seminars with printed sources
- ☐ Standard textbooks
- ☐ Regular work with archival materials
- ☐ No intervention (waiting list)
- ☐ Other (specify): ______________________

Control intervention description: _________________________________

STUDY OUTCOMES

PRIMARY OUTCOMES

1. Historical knowledge:

- Measurement method: ______________________ (tests, exams, essays, projects)
- Instrument: ______________________ (test name, scales)
- Measurement time: before intervention / after intervention / after ___________
- Experimental group results: $M =$ _____ $SD =$ _____ $n =$ _____
- Control group results: $M =$ _____ $SD =$ _____ $n =$ _____
- p-value: ___________ / effect size: ___________

2. Understanding of historical concepts:

- Measurement method: ______________________
- Instrument: ______________________
- Results: _________________________________

SECONDARY OUTCOMES

3. Learning motivation:

- Measurement method: ______________________ (questionnaire, interview, observation)
- Instrument/scale: ______________________
- Results: _________________________________

4. Student engagement:

- Measurement method: ______________________
- Indicators: ______________________ (discussion participation, attendance, time on task)
- Results: _________________________________

5. Source work skills:

- Measurement method: ______________________
- Instrument: ______________________
- Results: _________________________________

6. Critical thinking skills:

- Measurement method: ______________________
- Instrument: ______________________
- Results: _________________________________

7. Technological literacy:

- Measurement method: ______________________
- Results: _________________________________

8. Ability to create historical narratives:

- Measurement method: ______________________
- Results: _________________________________

9. Other outcomes: ____

STATISTICAL ANALYSIS

Statistical methods used:

☐ t-test

☐ ANOVA

☐ Mann-Whitney U

☐ Kruskal-Wallis

☐ χ^2 (Chi-square)

☐ Regression analysis

☐ Effect size (Cohen's d, η^2)

☐ Other: ______________________

Significance level: $p <$ ___________
Software: SPSS / R / SAS / Stata / other: ________________

QUALITATIVE DATA (if applicable)

Qualitative data collection methods:

☐ Interviews

☐ Focus groups

☐ Observation

☐ Analysis of documents/student reflections

☐ Other: ______________________

Main themes/conclusions: _______________________________________

AUTHORS' CONCLUSIONS

Main conclusions regarding effectiveness: _________________________________

____

Authors' recommendations: _______________________________________

____

Study limitations (noted by authors): ____________________________

____

STUDY QUALITY ASSESSMENT

Risk of bias:

- Randomization: low / high / unclear risk
- Allocation concealment: low / high / unclear risk
- Blinding of participants: low / high / unclear risk
- Blinding of outcome assessors: low / high / unclear risk
- Incomplete outcome data: low / high / unclear risk
- Selective reporting: low / high / unclear risk

Overall quality assessment: high / moderate / low

ADDITIONAL NOTES

Conflict of interest: present / absent / not specified
Ethical approval: obtained / not required / not specified
Additional reviewer comments: ________________________________

____

____

Map completion date: ______________________
Reviewer: ________________________________

D. Studies excluded at full-text assessment stage

1. Soh et al. [19]: "Digital histories for the digital age: Collaborative writing in large lecture courses"
2. Davis et al. [8]: "Faculty–library collaborations in digital history: A case study of the travel journal of Cornelius B. Gold"
3. Maslova et al. [54]: "Methods of Working with Local Digital Resources on History: Foreign Experience and Russian Practices"
4. Frith and Richter [55]: "Building participatory counternarratives: Pedagogical interventions through digital placemaking"
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14. Thomas and Harden [61]: “The history harvest: An experiment in democratizing the past through experiential learning”
15. Woodring and Fox-Horton [62]: “History Harvesting: A Case Study in Documenting Local History”
16. Lewis and Taylor-Poleskey [63]: “Hidden Town in 3D: Teaching and Reinterpreting Slavery Virtually at a Living History Museum”
17. McLean et al. [18]: “Spaces of collaboration: The poetics of place and historical consciousness”

A specialized Ukrainian-Polish computer science translator for primary education: Design and implementation

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Abstract

As a result of the full-scale Russian invasion of Ukraine that began on February 24, 2022, a large number of Ukrainians were forced to leave their homes and seek refuge in other countries, particularly in Poland. Many Ukrainian children found themselves in a difficult situation, continuing their education in Ukrainian schools remotely while also attending Polish schools offline. This parallel education in two school systems and languages creates challenges for students, especially in understanding and using the specialised terminology of school subjects like computer science. To address this issue, we propose creating a specialised Ukrainian-Polish dictionary of computer science terms for primary school students. This study aims to design and implement a Ukrainian-Polish online dictionary of computer science terms to support the bilingual education of Ukrainian primary school students in Poland, helping overcome language barriers and terminological challenges and aiding adaptation to the new educational environment.

Keywords

Ukrainian-Polish computer science translator, primary education, bilingual education, computer science terminology, refugee education, language barrier, educational technology, online translator

1. Introduction

As a result of the full-scale Russian invasion of Ukraine that began on February 24, 2022, a large number of Ukrainians were forced to leave their homes and seek refuge in other countries (as of 16.05.2024 - 6,483,500 people [1]). In particular, a significant number of Ukrainian women (43.75% of all who left) with school-age children (31.93% aged 5 to 17 years), including primary school students, migrated to Poland.

These children found themselves in a difficult situation, continuing their education in Ukrainian schools remotely while also attending Polish schools offline [2]. Such parallel education in two school systems and languages creates challenges for students [3], especially in understanding and using the specialised terminology of school subjects.

In particular, this applies to computer science – a subject filled with a large number of specific terms. In Ukrainian schools, computer science is studied as a separate subject from the 3rd grade [4], while in Poland – from the 1st grade [5].

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All this leads to problems with understanding and communication in computer science lessons, complicates students' learning of the material and creates psychological discomfort from uncertainty in their own knowledge. This problem is especially acute for primary school students who are just beginning to become familiar with computer science.

To solve this problem, a specialised Ukrainian-Polish dictionary of computer science terms for primary school students is proposed. Such a dictionary will help students systematise and compare the terminology of the two languages, improve their understanding of the subject, and facilitate communication in computer science lessons in Polish schools.

Moreover, to facilitate the use of the dictionary, an online translator based on it is planned, which will be a useful tool for both students and teachers. The interactivity and accessibility of the online translator will allow quick finding of the necessary terms and viewing options for their translation and interpretation.

The purpose of the study – design and implementation of a Ukrainian-Polish online translator of computer science terms for primary school students.

According to the purpose, the main **objectives of the study** are defined as follows:

1. To extract computer science terminology from computer science textbooks for primary school students in Poland and Ukraine for compiling a dictionary.
2. To design and implement an online translator based on the created dictionary.

Research methods:

- *search* for computer science textbooks for primary school students in Polish and Ukrainian;
- *analysis* of textbook content to find terms or terminological dictionaries;
- *synthesis* of dictionaries: a) terms in Ukrainian and Polish with full correspondence (for translation); b) terms in Ukrainian that do not have a complete equivalent in Polish (for interpretation); c) terms in Polish that do not have a complete equivalent in Ukrainian (for interpretation);
- *software engineering methods* for designing and implementing an online translator.

2. Extraction of Ukrainian and Polish computer science terminology from primary school computer science textbooks

2.1. Analysis of educational programmes and textbooks on computer science for primary schools in Ukraine

The article [6] discusses the importance of information technology in modern society, which leads to an increase in the number of countries introducing information technology even in primary schools. In particular, it emphasises that the content of curricula often includes digital literacy and computer science, confirming the importance of these aspects in primary education.

According to the State Standard of Primary Education, the aim of the informatics educational field is the formation of information and communication competence and other key competencies, the ability to solve problems using digital devices, information and communication technologies and critical thinking for development, creative self-expression, own and social well-being, skills of safe and ethical activity in the information society [4].

The purpose of computer science education in grades 1-2 is the diverse development of the child's personality and his/her worldview orientations, the formation of information and other key competencies necessary for life and further education [7].

Computer science educational programmes for grades 2-4 are developed in accordance with the State Standard of Primary Education and approved by the Ministry of Education and Science of Ukraine.

A request to Claude 3 regarding the comparison of typical educational programmes on computer science for grades 1-2, developed under the guidance of O. Ya. Savchenko [7] and R. B. Shyian [8], provided an opportunity to summarise their common features:

- the goal is to form information competence and develop logical, algorithmic, and creative thinking in students;
- attention is paid to the formation of skills to find, process, store and present information;
- they include topics about digital devices, their safety, and ethics in the information space;
- they provide for the acquisition of practical skills in working with graphic and text editors.

Table 1 shows the differences and features of the programmes [7] and [8].

Table 1
Differences and features of programmes for grades 1-2 [7] and [8].

Programme [7]	Programme [8]
Built linearly-concentrically with horizontal deepening	Built on 5 content lines
Study of computer science from 2nd grade	Study of computer science from 1st grade
Includes approximate objects and teaching aids	Contains more detailed proposed content and expected results
Provides for the study of a programming environment from 3-4 grades	Does not include a programming environment

A request to Claude 3 regarding the comparison of typical educational programmes on computer science for grades 3-4, developed under the guidance of O. Ya. Savchenko [9] and R. B. Shyian [10], provided an opportunity to summarise their common features:

- the goal is to form information and communication competence, skills to work with information, use digital devices and programs;
- they provide for the formation of algorithmic thinking, creation of simple programs and understanding of the principles of functioning of digital devices;
- they lay the foundations for safe and ethical behaviour in the information environment.

Table 2 shows the differences and features of the programmes developed under the guidance of O. Ya. Savchenko and R. B. Shyian.

Table 2
Differences and features of programmes for grades 3-4 [9] and [10].

Programme [9]	Programme [10]
The content is presented along the following content lines: "Information. Actions with Information", "Computer Devices for Performing Actions with Information", "Object. Object Properties", "Creation of Information Models. Changing Ready-Made Ones. Use", "Algorithms".	The content is presented along the following content lines: "Me in the World of Information (Data. Information. Models)", "My Digital Creativity", "Communication and Collaboration", "Me and Digital Devices", "Responsibility and Safety in the Information Society".
Emphasis on forming skills for creating and editing information objects	Greater emphasis on developing critical thinking and evaluating information
Robotics is not mentioned	A review of robotics designers is mentioned
The use of digital devices for orientation in space and time is not mentioned	The use of digital devices for orientation in space and time is provided

To find out the common and different computer science terminology used in the programmes [7, 8, 9, 10], all computer science terms used in them were extracted. The analysis of the extracted terms provided the opportunity to distinguish computer science terminology:

- for grades 3-4, unique to the program under the guidance of R. B. Shyian: web resource, information properties, hypertext, information resource, information processes, combined tasks, network culture, logical sequence, network community, network navigation, table operations, Internet connection, plagiarism, simple algorithms, element structuring, fake, digital reputation, digital trace;

- for grades 3-4, unique to the programme under the guidance of O. Ya. Savchenko: animation effects, website, virtual library, directory, text bookmarks, information interaction, editing commands, critical evaluation of information, mathematical model, message carriers, organisation of digital device operation, computer memory, message, programme, project, algorithm execution environment, text reading environment, decoding symbols, encoding symbols, object components, dictionary;
- for grades 3-4, common to the programme under the guidance of O. Ya. Savchenko and R. B. Shyian: browser, information object, command, computer presentations, linear algorithm, Internet, information search, search engines, presentation editing, branched algorithm, programming environment, logical sequence system, complex algorithm, information distortion, judgement, text object;
- for grades 1-2, unique to the programme under the guidance of R. B. Shyian: object properties, encyclopaedia, information signs, password, PIN code, software environment;
- cross-cutting for grades 1-4, unique to the programme under the guidance of R. B. Shyian: information security, computer systems, modern information carriers, fact;
- cross-cutting for grades 1-4 according to the programme under the guidance of R. B. Shyian, used in grades 3-4 according to the programme under the guidance of O. Ya. Savchenko: design, sequence of events, sequence ordering;
- for grades 1-2, unique to the programme under the guidance of O. Ya. Savchenko: graphic information, graphic algorithm, computer programme menu;
- cross-cutting for grades 1-4, unique to the programme under the guidance of O. Ya. Savchenko: copyright, geometric model, geometric tasks, information networks, tabular model form;
- cross-cutting for grades 1-4 according to the programme under the guidance of O. Ya. Savchenko, used in grades 3-4 according to the programme under the guidance of R. B. Shyian: hyperlink;
- for grades 1-2, common to the programme under the guidance of O. Ya. Savchenko and R. B. Shyian: information sources, information and communication technologies, computer devices, data carriers, event, text information;
- cross-cutting for grades 1-4 according to the programme under the guidance of O. Ya. Savchenko, used in grades 1-2 according to the programme under the guidance of R. B. Shyian: graphic object;
- cross-cutting for grades 1-4 according to the programmes under the guidance of O. Ya. Savchenko and R. B. Shyian: algorithm, Internet safety, graphic editor, information storage, computer science, information, information model, computer programmes, model, object model, object, table, text, text editor.

No computer science terminology was found for:

- for grades 1-2 according to the programme under the guidance of R. B. Shyian, used in grades 3-4 according to the programme under the guidance of O. Ya. Savchenko;
- for grades 1-2 according to the programme under the guidance of O. Ya. Savchenko, used in grades 3-4 according to the programme under the guidance of R. B. Shyian;
- cross-cutting for grades 1-4 according to the programme under the guidance of R. B. Shyian, used in grades 1-2 according to the programme under the guidance of O. Ya. Savchenko.

A review of the current textbooks [11] showed that computer science education in grades 1-3 is carried out using the textbooks "I Explore the World", and in grade 4 – using the textbooks "Computer Science".

In the 2023-2024 academic year, the Ministry of Education and Science of Ukraine recommended the following computer science textbooks for grade 4:

- according to the programme under the guidance of O. Ya. Savchenko [9]: Morze and Barna [12], Hilberg et al. [13], Korshunova [14], Vorontsova et al. [15], Kornienko et al. [16], Vdovenko [17].
- according to the programme under the guidance of R. B. Shyian [10]: Andrusych and Stetsenko [18], Kozak [19], Lomakovska and Protsenko [20].

Analysis of the table contains all the computer science terms used in the specified textbooks and programmes provided an opportunity to determine potential problems for each pair of the form "textbook – programme", namely mandatory terms present in the programmes but absent in the textbook, and optional terms absent in the programme but present in the textbook:

- – terms provided by the programme [9] but missing in the textbook by Morze and Barna [12]: algorithm, animation effects, Internet safety, browser, website, hyperlink, graphic editor, directory, text bookmarks, information storage, computer science, information interaction, information model, information objects, information, command, editing command, computer presentation, computer programme, design, critical evaluation of information, linear algorithm, mathematical model, Internet, model (25);
  – terms not provided by the programme [9] but present in the textbook by Morze and Barna [12]: copyright, input information, hypertext, game, graphic object, data, space, software, project, processor, robot, site, script, slide, smartphone, scene in "Scratch", condition, loop, digital devices, artificial intelligence (20);
- – terms provided by the programme [8] but missing in the textbook by Kozak [19]: algorithm, web resource, graphic editor, computer science, computer presentation, computer programme, Internet, information search, branched algorithm, programming environment, logical sequence system, information distortion, text editor, sequence ordering, fake (15);
  – terms not provided by the programme [8] but present in the textbook by Kozak [19]: URL address, account, browser window, game, graphic object, information sources, experience, emoticons, keywords, integrity criteria for information, integrity criteria for messages, nickname, office software package, portable storage device, plagiarism, message, mail server, file transfer protocol, processor, robot, sprite, scene in "Scratch", file, text formatting, cyclic algorithm, digital reputation, digital data, digital devices (28);
- – terms provided by the programme [9] but missing in the textbook by Kornienko et al. [16]: animation effects, virtual library, directory, text bookmarks, information interaction, information objects, information, editing command, computer programme, linear algorithm, mathematical model, Internet, model, object model, information search, presentation editor, branched algorithm, programming environment, logical sequence system, information distortion, table, text, text editor, sequence ordering (24);
  – terms not provided by the programme [9] but present in the textbook by Kornienko et al. [16]: loop algorithm, branch algorithm, antivirus programme, web page, executor, algorithm executor, command executor, input information, information sources, designer, modern user experience, collage, integrity criteria for software elements, message, error, portfolio, presentation, receiver, software, programming, abstracting, branched structure, slide, condition, file, fact (26);
- – terms provided by the programme [9] but missing in the textbook by Vdovenko [17]: animation effects, Internet safety, virtual library, hyperlink, directory, text bookmarks, information storage, information interaction, information, command, computer presentation, design, critical evaluation of information, mathematical model, Internet, object model, object, sequence of events, information search, logical sequence system, complex algorithm, information distortion, table, text editor, sequence ordering (25);
  – terms not provided by the programme [9] but present in the textbook by Vdovenko [17]: paragraph, copyright, academic integrity, branch algorithm, audio file, web page, executor, video file, internal memory, geoboard, hypertext, graphic model, graphic object, software uninstallation, information processes, encoding, computer animation, computer model, integrity criteria for animation, integrity criteria for data, integrity criteria for objects, logical sequence, positioning, project, text editing, text positioning, style, navigation page, storytelling, tester (30);
- – terms provided by the programme [8] but missing in the textbook by Lomakovska and Protsenko [20]: algorithm, Internet safety, browser, web resource, graphic editor, informa-

tion storage, information model, information objects, computer programme, design, linear algorithm, Internet, model, object model, object, sequence of events, information search, search engine, presentation editor, branched algorithm, logical sequence system, text, fact, fake, legal responsibility (25);

  - terms not provided by the programme [8] but present in the textbook by Lomakovska and Protsenko [20]: paragraph, web page, executor, graphic object, chart, modern programme user experience, information gathering, information systems, service information, keywords, plagiarism, connector, file extension, system unit, scanner, slide, verbal model, ways of presenting messages, flash drive, flash storage device (20);

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  - terms provided by the programme [9] but missing in the textbook by Vorontsova et al. [15]: animation effects, Internet safety, browser, virtual library, directory, text bookmarks, information storage, computer science, information interaction, information model, information objects, information, command, editing command, computer presentation, critical evaluation of information, mathematical model, Internet, object model, sequence of events, information search, search engine, presentation editor, branched algorithm, logical sequence system, complex algorithm, table, text (28);
  - terms not provided by the programme [9] but present in the textbook by Vorontsova et al. [15]: RGB model, auto shape, branch algorithm, animation, clipboard, data input, data output, video editor, properties, object properties, input information, hypertext, software uninstallation, information sources, range, domain, user experience, hard magnetic disk, variable, computer virus, nickname, folder, portable storage device, personal data, confirmation, event, presentation, input devices, output devices, programmer, software, programming, site, text model, word processor, slide theme, title slide, improved experience of programme users, inference, fact, fake, paragraph formatting, false message, loop, font(45);

-
  - terms provided by the programme [9] but missing in the textbook by Korshunova [14]: animation effects, website, hyperlink, graphic editor, directory, text bookmarks, information storage, information interaction, information model, information objects, information, command, editing command, computer presentation, computer programme, design, critical evaluation of information, linear algorithm, mathematical model, Internet, model, object model, information search, search engine, presentation editor, branched algorithm, programming environment, logical sequence system, complex algorithm, information distortion, table, text, text editor (33);
  - terms not provided by the programme [9] but present in the textbook by Korshunova [14]: animation, byte, bit, flowchart, built-in programmes, web page, winning strategy, statement, video information, measurement, information properties, object properties, geolocation, graphic information, data, sensor, binary encoding, domain, modern programme user experience, personal information, integrity criteria for statements, integrity criteria for facts, nickname, operator, folder, personal data, icon, project, robot, fact (30);

  - terms provided by the programme [9] but missing in the textbook Hilberg et al. [13]: animation effects, website, virtual library, graphic editor, directory, computer science, information interaction, information model, information objects, command, editing command, computer presentation, computer programme, design, critical evaluation of information, linear algorithm, mathematical model, Internet, object model, object, sequence of events, information search, search engine, presentation editor, branched algorithm, programming environment, logical sequence system, complex algorithm, information distortion, judgement, table, text, text editor, sequence ordering (34);
  - terms not provided by the programme [9] but present in the textbook Hilberg et al. [13]: input information, data, software uninstallation, electronic document, electronic textbook, general personal data, information storage, gathering, audio information, message, information presentation, event, resource, file, cloud environment, digital society, digital devices (17);

– terms provided by the programme [8] but missing in the textbook by Andrusych and Stetsenko [18]: algorithm, browser, web resource, hyperlink, information storage, computer science, information model, information objects, information, command, computer presentation, design, linear algorithm, Internet, model, object model, object, information search, search engine, presentation editor, programming environment, logical sequence system, complex algorithm, text, text editor, sequence ordering, fact, fake, legal responsibility (29);
– terms not provided by the programme [8] but present in the textbook by Andrusych and Stetsenko [18]: Morse code, branch algorithm, algorithmic structures, nested branching, gadget, data, sensor, culture, Internet connection, message, event, presentation, LED, pie chart, touch screen, symbol and text information, instant messaging systems, social network, community, observation (20);

Additionally, mandatory terms missing from all considered textbooks were identified:

• according to the programme under the guidance of O. Ya. Savchenko [9]: animation effects, directory, information interaction, mathematical model, Internet, object model, information search, logical sequence system, table;
• according to the programme under the guidance of R. B. Shyian [10]: algorithm, web resource, Internet, information search, logical sequence system, fake.

A quantitative summary of the obtained results is presented in table 3. Textbooks with the minimum number of missing and redundant terms are marked in yellow, and those with the next minimum number are marked in silver.

Table 3
Evaluation of computer science textbooks for grade 4 by terminological completeness and redundancy.

Textbook	**Number of terms present in the programme but missing in the textbook**	**Number of terms missing in the programme but present in the textbook**	**Total number**
Morze and Barna [12]	25	20	45
Kozak [19]	28	24	52
Kornienko et al. [16]	24	26	50
Vdovenko [17]	25	30	55
Lomakovska and Protsenko [20]	25	20	45
Vorontsova et al. [15]	28	45	73
Korshunova [14]	33	30	63
Hilberg et al. [13]	34	17	51
Andrusych and Stetsenko [18]	29	20	49

Table 3 clearly shows that according to the programme [9], the most terminologically complete textbook is the textbook by the author team led by Kornienko et al. [16], and the least redundant is the textbook by Hilberg et al. [13]. However, on average, the textbook by the author team led by Morze and Barna [12] is ahead in terms of completeness and redundancy of terms. According to the programme [8], the most terminologically complete textbook is the textbook by the author team led by Lomakovska and Protsenko [20], and the least redundant are the textbooks by Hilberg et al. [13] and Andrusych and Stetsenko [18]. However, on average, the textbook by the author team led by Lomakovska and Protsenko [20] is ahead in terms of completeness and redundancy of terms.

The expert evaluation method was used to determine textbook ratings based on terminological completeness and redundancy. Two experts were asked to evaluate them on a Likert scale from -2 (not at all important) to +2 (extremely important).

The experts' answers to the questionnaire are given in table 4.

Table 4
Experts' ratings based on the questionnaire results.

Question	Expert 1	Expert 2	Average
Rate the importance of the terminological completeness of the textbook (how important is it that all terms present in the programme are in the textbook?)	+2	+2	2
Rate the importance of the terminological redundancy of the textbook (how important is it that the textbook has as few additional terms as possible that are absent in the programme?)	0	-1	-0.5

Accordingly, to determine the rating score of textbooks, it is necessary to subtract half the number of terms absent in the programme but present in the textbook from twice the number of terms present in the programme but absent in the textbook. The ranking results are presented in table 5.

Table 5
Evaluation of computer science textbooks for grade 4 by terminological completeness and redundancy.

Place	Textbook	Number of terms present in the programme but missing in the textbook	Number of terms missing in the programme but present in the textbook	Rating score
1	Vorontsova et al. [15]	28	45	33.5
2	Kornienko et al. [16]	24	26	35
2	Vdovenko [17]	25	30	35
3	Morze and Barna [12]	25	20	40
3	Lomakovska and Protsenko [20]	25	20	40
4	Kozak [19]	28	24	44
5	Andrusych and Stetsenko [18]	29	20	48
6	Korshunova [14]	33	30	51
7	Hilberg et al. [13]	34	17	59.5

2.2. Analysis of computer science curricula and textbooks in Poland

Primary education in Poland is compulsory and lasts 8 years. The obligation to attend school begins at the beginning of the school year in the calendar year in which the child turns 7 years old. Primary education is divided into two stages [21]:

- initial stage (grades 1-3) – duration of 3 years;
- second stage (grades 4-8) – duration of 5 years.

For each stage of primary education, there is a core curriculum that defines the compulsory subjects and expected learning outcomes [21]:

- for grades 1-3, the core subjects are Polish language, mathematics, natural science, music, art, technology, computer science, physical education, and ethics.
- for grades 4-8, the following subjects are added: history, social studies, biology, geography, physics, chemistry, second foreign language.

The early education curriculum is focused on [22]:

- the child-student together with his/her needs, interests and abilities;
- individual and group learning in cooperation and interaction;
- reflection, research, creativity, activity, acquisition of new skills;

- understanding of acquired knowledge, formation and improvement of skills.

The core curriculum of primary school defines the following tasks of general education for grades 1-3 [23]:

1) students gain basic knowledge about facts, principles, theory and practice, mainly related to topics and phenomena closely related to students' experience;
2) students acquire skills to use their knowledge in performing tasks and solving problems;
3) students form attitudes that determine effective and responsible existence in the modern world.

The curriculum for grades 4-8 [24] defines the main objectives of teaching computer science to students as:

- development of logical, algorithmic and abstract thinking;
- mastering programming skills and solving problems using computers and digital devices;
- acquiring skills to effectively use computers, digital devices and computer networks;
- development of competencies of cooperation, communication and project management, including in virtual environments;
- adherence to security principles, ethical norms, data protection, intellectual property and responsible attitude to the use of technologies;
- application of computer science and ICT to solve problems from various fields of knowledge;
- preparation for future professional activities related to the use of information technologies;
- mastering the skills of creating various digital content: texts, presentations, multimedia, web pages;
- development of skills in searching, analysing, and critically evaluating information and its sources;
- familiarisation with the historical development of computer science and information technologies.

To extract computer science terms from Polish computer science textbooks, textbooks for 4th grade (Jochemczyk et al. [25], Koba et al. [26]), 5th grade (Kęska [27]), 6th grade (Jochemczyk et al. [28]), 7th grade (Jochemczyk et al.) and 8th grade (Koba [29]) were analysed.

2.3. Extraction and systematisation of computer science terms in Ukrainian and Polish

For institutions of general secondary education in Ukraine with Polish as the language of instruction, the Ministry of Education and Science of Ukraine recommends a Ukrainian-Polish and Polish-Ukrainian dictionary [30]. The main task of the dictionary is to help students correlate terms in their native language with terms in the Ukrainian language and vice versa, which is especially important in the current conditions [30, p. 3].

Analysis of the Ukrainian computer science terminology presented in the programmes and textbooks, the Polish computer science terminology of textbooks and the Ukrainian-Polish dictionary of computer science terminology provided an opportunity to:

a) extract 48 terms present in Ukrainian computer science programmes and textbooks but absent in the dictionary proposed by the Ministry of Education and Science (table 6);
b) extract 60 terms present in Polish computer science textbooks but absent in the dictionary proposed by the Ministry of Education and Science (table 7).

Table 6: Ukrainian terms missing in the dictionary [30] and their proposed Polish translations.

No.	Ukrainian / English term	Proposed Polish translation
1	Анімаційні ефекти / Animation effects	Efekty animacyjne
2	Віртуальна бібліотека / Virtual library	Wirtualna biblioteka

Continuation of table 6

No.	Ukrainian / English term	Proposed Polish translation
3	Геолокація / Geolocation	Geolokalizacja
4	Геоборд / Geoboard	Geoboard
5	Графічна інформація / Graphic information	Informacja graficzna
6	Графічна модель / Graphic model	Model graficzny
7	Джерела інформації / Information sources	Źródła informacji
8	Діапазон / Range	Zakres
9	Довідник / Directory	Podręcznik
10	Досвід користувача / User experience	Doświadczenie użytkownika
11	Досвід сучасних користувачів / Modern user experience	Doświadczenie współczesnych użytkowników
12	Досвід сучасних користувачів програм / Modern program user experience	Doświadczenie współczesnych użytkowników programów
13	Загальні дані про особу / General personal data	Ogólne dane osobowe
14	Звукова інформація / Audio information	Informacja dźwiękowa
15	Збирання інформації / Information gathering	Gromadzenie informacji
16	Збирання / Gathering	Zbieranie
17	Змінна / Variable	Zmienna
18	Інформаційна взаємодія / Information interaction	Interakcja informacyjna
19	Інформація про особу / Personal information	Informacje o osobie
20	Інформація про послуги / Service information	Informacje o usługach
21	Інформаційні процеси / Information processes	Procesy informacyjne
22	Кодування / Encoding	Kodowanie
23	Комбіновані задачі / Combined tasks	Zadania kombinowane
24	Логічне слідування / Logical sequence	Następstwo logiczne
25	Математична модель / Mathematical model	Model matematyczny
26	Мережева спільнота / Network community	Społeczność sieciowa
27	Носії повідомлень / Message carriers	Nośniki komunikatów
28	Операції з таблицями / Table operations	Operacje na tabelach
29	Організація роботи цифрового пристрою / Organization of digital device operation	Organizacja pracy urządzenia cyfrowego
30	Підключення до Інтернету / Internet connection	Połączenie z internetem
31	Подання інформації / Information presentation	Prezentowanie informacji
32	Помилка / Error	Błąd
33	Прості алгоритми / Simple algorithms	Proste algorytmy
34	Проєкт / Project	Projekt
35	Символи декодування / Decoding symbols	Symbole dekodowania
36	Символи кодування / Encoding symbols	Symbole kodowania
37	Складові частини об’єктів / Object components	Składowe obiektu
38	Словник / Dictionary	Słownik
39	Структурування елементів / Structuring of elements	Strukturyzacja elementów
40	Сучасні носії інформації / Modern information carriers	Współczesne nośniki informacji
41	Тестувальник / Tester	Tester
42	Удосконалений досвід користувачів програм / Improved user experience of programs	Ulepszone doświadczenie użytkownika programów
43	Фейк / Fake	Fake news

Continuation of table 6

No.	Ukrainian / English term	Proposed Polish translation
44	Цифрова репутація / Digital reputation	Reputacja cyfrowa
45	Цифрове суспільство / Digital society	Społeczeństwo cyfrowe
46	Цифрові дані / Digital data	Dane cyfrowe
47	Цифрові пристрої / Digital devices	Urządzenia cyfrowe
48	Цифровий слід / Digital trace	Ślad cyfrowy

Table 7: Polish terms missing in the dictionary [30] and their proposed Ukrainian translations.

No.	Polish term	Proposed Ukrainian / English translation
1	Adres komórki	Адреса комірки / Cell address
2	Algorytm porządkowania	Алгоритм упорядкування / Sorting algorithm
3	Algorytm wyszukiwania	Алгоритм пошуку / Search algorithm
4	Analizowanie danych	Аналіз даних / Data analysis
5	Animacja Duszka	Анімація Спрайта / Sprite animation
6	Animacja obiektu slajdu	Анімація об'єкта слайда / Slide object animation
7	ASCII	ASCII / ASCII
8	Bajt	Байт / Byte
9	Biezpieczna praca w komputerze	Безпечна робота на комп'ютері / Safe computer work
10	BIOS	BIOS / BIOS
11	Binarny system	Двійкова система / Binary system
12	Blok	Блок / Block
13	Blu-Ray dysk	Blu-Ray диск / Blu-Ray disc
14	Chmura internetowa	Інтернет-хмара / Internet cloud
15	Chronometraż	Хронометраж / Timing
16	Częstotliwość procesora	Частота процесора / Processor frequency
17	Decymalny system	Десяткова система / Decimal system
18	Dokumenty Google	Документи Google / Google Docs
19	Dysk twardy	Жорсткий диск / Hard drive
20	Edycja Tekstu	Редагування тексту / Text editing
21	Edytor grafiki	Редактор графіки / Graphics editor
22	Edytor obrazów	Редактор зображень / Image editor
23	Edytor wideo	Відеоредактор / Video editor
24	Efect 3D	3D-ефект / 3D effect
25	Efect przejścia	Ефект переходу / Transition effect
26	Emoticon	Емотикон / Emoticon
27	Filtrowanie danych	Фільтрування даних / Data filtering
28	Flooding	Флудинг / Flooding
29	Formularz konta	Форма облікового запису / Account form
30	Formatowanie Tabeli	Форматування таблиці / Table formatting
31	GNU	GNU / GNU
32	Grupowanie obiektów	Групування об'єктів / Object grouping
33	Hiperłącze	Гіперпосилання / Hyperlink
34	Historia informatyki	Історія інформатики / History of informatics
35	Importowanie obrazu	Імпортування зображення / Image importing
36	Infografika	Інфографіка / Infographics

Continuation of table 7

No.	Polish term	Proposed Ukrainian / English translation
37	Instalator	Інсталятор / Installer
38	Jasność obrazu	Яскравість зображення / Image brightness
40	Kalkulator systemowy	Системний калькулятор / System calculator
41	Kolumna tekstu	Колонка тексту / Text column
42	Krzyżówki	Кросворди / Crosswords
43	Ksztalty 3D	3D-фігури / 3D shapes
44	Łancuszek internetowy	Інтернет-ланцюжок / Internet chain
45	Logogryfy	Логогрифи / Logogriphs
46	Netykieta	Мережевий етикет / Netiquette
47	Oprogramowanie demonstracyjne	Демонстраційне програмне забезпечення / Demo software
48	Oprogramowanie licencjonowane	Ліцензійне програмне забезпечення / Licensed software
49	Pamięć trwala	Постійна пам'ять / Permanent memory
50	Pisak duszka	Олівець спрайта / Sprite pen
51	Przęglądarka internetowa	Інтернет-переглядач / Internet browser
52	Scena	Сцена / Scene
53	Scratch	Скретч / Scratch
54	Seria danych	Серія даних / Data series
55	Skrypt zielonej flagi	Скрипт зеленого прапора / Green flag script
56	Sortowanie danych	Сортування даних / Data sorting
57	Sterowanie obiektem	Керування об'єктом / Object control
58	Tło sceny	Тло сцени / Scene background
59	Tło scenyykres słupkowy	Стовпчикова діаграма / Bar chart
60	Writer	Writer / Writer

3. Design and implementation of a Ukrainian-Polish online dictionary of computer science terms for primary school students

3.1. Requirements for the online translator

The target audience of the online translator users is Ukrainian primary school students who are temporarily staying in Poland due to the military actions in Ukraine.

Usage scenarios of the translator:

1. A student enters a Ukrainian computer science term, and the translator provides a Polish translation to facilitate communication and learning in the new environment.
2. A student enters a Polish computer science term, and the translator provides a Ukrainian translation to understand the learning material.

Functional requirements for the translator:

1. The translator should have a field for entering terms.
2. The translator should support translation from both Ukrainian to Polish and Polish to Ukrainian.
3. The translator should display the translation in a separate field.

Non-functional requirements for the translator:

1. The translator interface should be intuitive and easy to use for students.

2. The translator should be free and available online.
3. The translator should provide a fast and accurate translation.
4. The translator should contain adapted vocabulary, taking into account the level of primary school.

3.2. Design of the online translator

Three main web development technologies were used to create the Ukrainian-Polish online translator of computer science terms: HTML, CSS, and JavaScript.

HTML was used to structure and present the content of the index.html file, which contains the HTML markup of the main page of the online translator, including the header, fields for entering a term and displaying the translation, translation buttons, and a selection of the translation direction (figure 1).

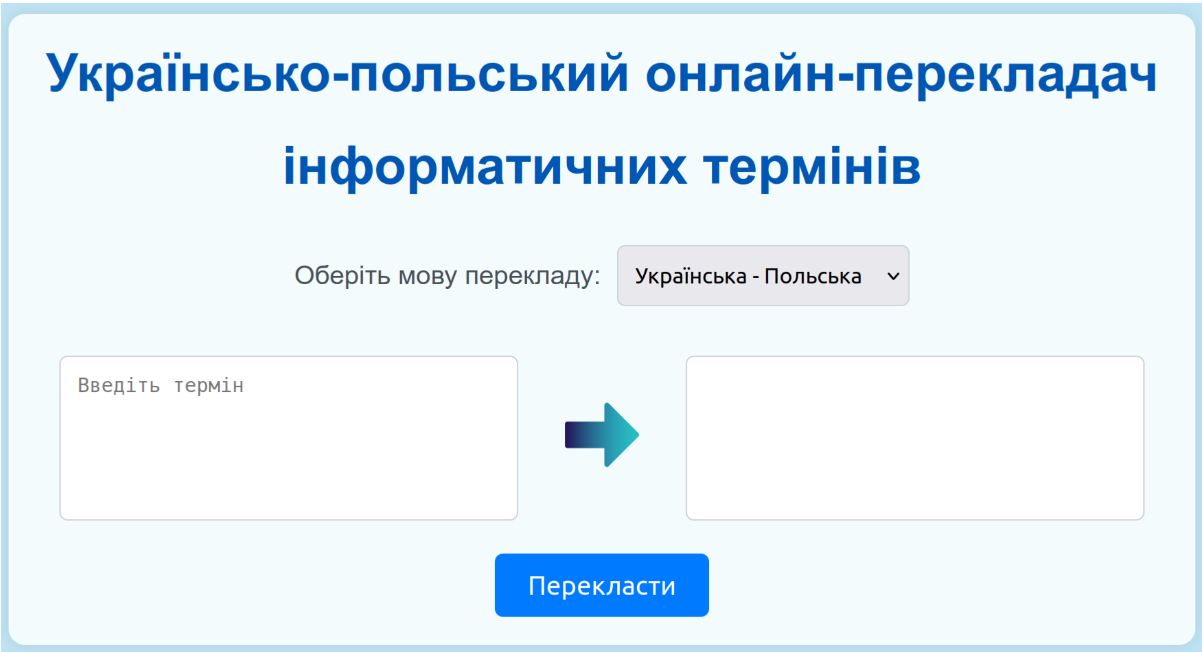

Figure 1: Interface of the online translator.

The styles.css file is responsible for styling and formatting the page elements, such as colours, fonts, placement, and layout.

To ensure the convenience and clarity of the interface for the target audience of primary school students, the following aspects were considered:

- *simplicity and minimalism* – the interface has only the necessary elements to perform the main function of translating terms, without extra details and distractions.
- *clear names and hints* – all interface elements have clear and understandable names, and text fields contain hints to facilitate understanding of their purpose;
- *contrasting colours and readable fonts* – to ensure readability and highlight important elements, contrasting colours and clear fonts with appropriate sizes were chosen;
- *responsive design* – the interface adapts to different screen sizes and devices (computers, tablets, smartphones), ensuring convenient use in any environment.

The script.js file implements the functionality of term translation and interaction with the dictionary.json database, in which Ukrainian terms are used as keys and their Polish translations as corresponding values.

3.3. Implementation of the online translator

Visual Studio Code was used for development, and the Google Chrome web browser was used for testing and debugging.

Since the online translator is a client-side web application, developing a server part and API was not necessary.

The translation logic is implemented in the script.js file (https://github.com/Oleksandra121/kwalifikacyjna). The key function is translateTerm(), which is called when the "Translate" button is clicked. This function performs the following steps:

1. Retrieves the entered term and translation direction from the corresponding fields.
2. Loads the term dictionary dictionary.json using an asynchronous fetch request.
3. Check the availability of a translation for the entered term in the dictionary (figure 2).
4. Displays the translation or a message about the absence of a translation in the text field.

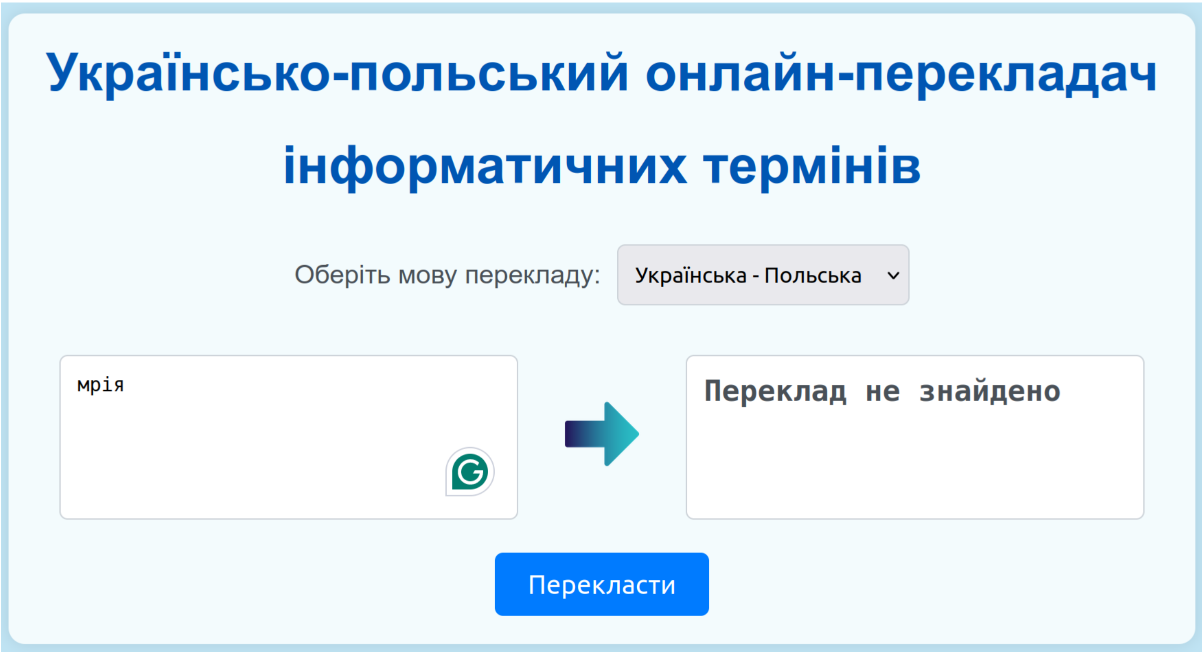

Figure 2: Operation of the online translator.

3.4. Testing the online translator

For testing, the online translator was deployed on GitHub Pages at the URL: https://oleksandra121.github.io/kwalifikacyjna/.

After completing the development, the online translator was tested to ensure correct operation and compliance with the requirements. Testing was conducted in different web browsers (Chrome, Firefox) and on different devices (computers, tablets, smartphones).

The following aspects were checked:

- correct display of the interface on different devices and screen sizes (figure 3);
- correct functioning of the translation direction selection;
- correct translation of terms in both directions (Ukrainian-Polish and Polish-Ukrainian);
- display of appropriate messages in case of the absence of a translation.

The developed Ukrainian-Polish online translator of computer science terms was compared with Google Translate [31] (table 8).

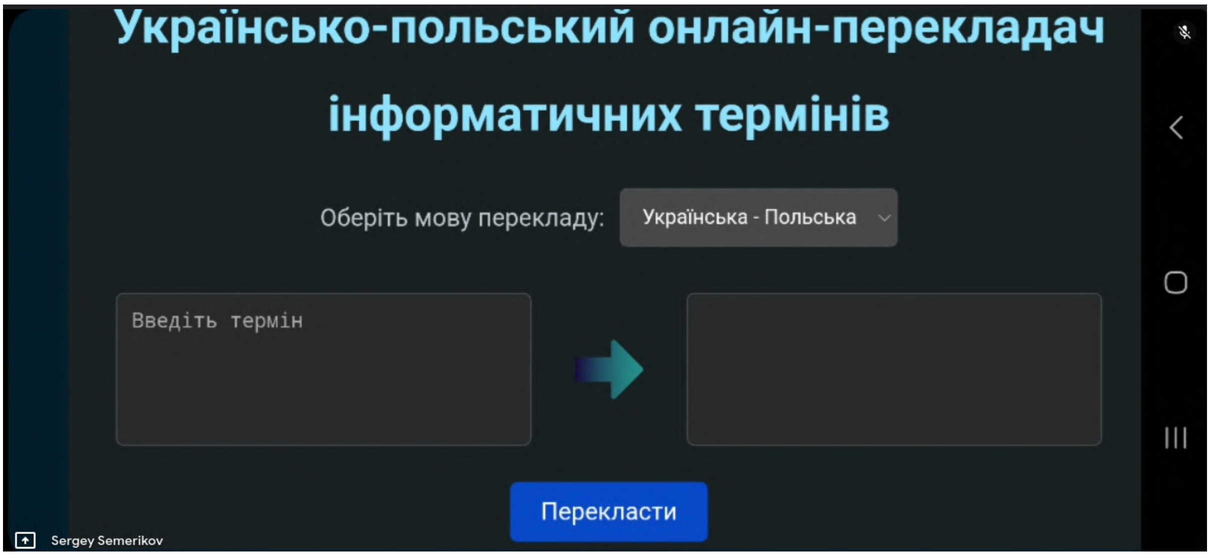

Figure 3: Testing the online translator on a mobile device.

Table 8
Comparison of the functionality of the created online translator and Google Translate.

Function	Ukrainian-Polish online translator of computer science terms	Google Translate
Specialization in IT terminology	+	–
Translation Ukr. $\rightleftharpoons$ Pol.	+	+
Term visualization	–	+
Pronunciation playback	–	+
Voice recognition	–	+
Offline mode	–	–
Adding custom terms	+	–

4. Conclusion

As a result of the research, a study of computer science terminology in computer science textbooks and curricula for primary schools in Ukraine and Poland was conducted. Based on this, a Ukrainian-Polish online translator of computer science terms for primary school students was designed and implemented.

The analysis of computer science curricula and textbooks for primary schools in Ukraine and Poland provided an opportunity to identify common and distinctive features in teaching the subject and investigate the terminological completeness and redundancy of Ukrainian textbooks relative to the curricula.

Extracting computer science terms from textbooks and comparing them with the Ukrainian-Polish dictionary recommended by the Ministry of Education and Science identified 48 Ukrainian and 60 Polish terms as missing in the dictionary. Their translation into Polish and Ukrainian, respectively, was proposed.

Based on the conducted research, an online translator of computer science terms in Ukrainian and Polish was designed and implemented. The application interface was developed taking into account the needs of the target audience – Ukrainian primary school students in Poland. The translator is free, available online, provides fast and accurate translation, and contains adapted vocabulary.

Testing the online translator confirmed its correct operation on different devices and browsers, and comparing it with Google Translator showed its competitive advantages in specializing in computer science terminology and the ability to expand the dictionary.

The obtained results can be used to further improve educational and methodological support for computer science and the development of Ukrainian-Polish educational cooperation. The online translator can become a useful tool for Ukrainian students in Poland, helping them overcome language barriers and adapt to the new educational environment.

Declaration on Generative AI

The authors have not employed any generative AI tools.

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The use of the digital environment of secondary school by parents in a blended learning format during the war in Ukraine

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Abstract

In this article, we raise a discussion about the use of the digital environment of secondary schools by parents of students as participants in the educational process in a blended learning format during the war. To collect the data, we used an online survey with 5224 respondents from all regions of Ukraine. The results of the study allowed to determine the readiness of parents to use the digital environment of their child's school; identify the needs and challenges faced by parents; find out how parents assess their child's skills in independent learning in distance education; determine the level of material and technical support in the family with a device for distance learning. The findings according to the majority of parents, the most critical aspects of improving the digital environment of the school are the renewal of material support, access to the Internet, communication, the use of a single online educational platform, the use of interactive teaching methods of digital learning tools, and ensuring information security. Additional analysis reveals that 34.6% of parents remain unaware of their school's educational platform, highlighting critical communication gaps. The study demonstrates that conducting a regular survey among parents is important in order to identify problem areas, increase trust and engagement, take into account the needs of educational participants, maintain the quality of the educational process and introduce innovations. The research provides evidence-based recommendations for schools, policymakers, and community organizations supporting education during crisis.

Keywords

secondary education, digital learning environment, parents, study, monitoring, blended learning, wartime education, Ukraine

1. Introduction

In modern society, we see how the progress of the digital society necessitates the constant and rapid development of digital education. The contemporary school is changing, and with it its digital learning environment (DLE) [1, 2, 3]. This applies to all components of the DLE, including the content and methods of teaching, technologies and teaching aids, digital resources, teaching support, tools for managing an educational institution, as well as communication and cooperation with all participants in the educational process (administration, teachers, students and parents of students).

To determine the effectiveness of the existing DLE of an educational institution, regular monitoring should be conducted among the participants of the educational process [4]. The monitoring system is effective in identifying and addressing issues that need to be improved in secondary education, it leads to improved functioning of key objects and actors through targeted interventions, and it helps to raise public awareness and improve education quality indicators [5]. Such work is especially important during the provision of general secondary education under martial law in Ukraine when the learning process in schools is carried out in different formats depending on the security situation in the region [6].

The war in Ukraine has fundamentally transformed the educational landscape, with parents assuming unprecedented roles in supporting their children's learning [7, 8, 9, 10]. Since February 2022, Ukrainian families have navigated educational disruption through varied learning formats: face-to-face instruction

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in safer regions, blended models in areas with intermittent security, and fully distance learning in frontline territories [11, 12, 13, 14]. This situation has positioned parents not merely as supporters but as essential mediators between schools and students, requiring them to master digital tools while managing war-related stress and displacement [15, 16, 17].

2. Literature review

The issues of the DLE in the secondary school are considered by Ovcharuk et al. [18], Pinchuk et al. [19], Taddeo and Barnes [20], Patton and Santos [21] who describe the organizational and pedagogical conditions of using the informational and digital environment. These foundational studies establish the theoretical framework for understanding digital environments in educational settings, though they were conducted before the current crisis context.

The use of digital tools and resources by secondary school teachers for the implementation of distance learning in Ukraine are covered by researchers of the Institute for Digitalisation of Education of the National Academy of Educational Sciences of Ukraine [22, 23, 24, 25, 26]. Their longitudinal research reveals evolving patterns of digital tool adoption, with significant acceleration during the COVID-19 pandemic that inadvertently prepared educators for wartime distance learning [27, 28, 29].

The challenges and needs of Ukrainian teachers in the use of digital tools for distance learning and professional development are revealed by Bobyliev and Vihrova [30], Ivaniuk and Ovcharuk [31, 32], Moiseienko et al. [33], Oleksiuk et al. [34], Ovcharuk et al. [11], Palamar et al. [35], Petrovych et al. [36], Ponomareva [37], Riabko et al. [38], Vlasenko et al. [39]. They highlight and compare the challenges faced by teachers during quarantine caused by COVID-19 pandemic and the war in Ukraine. Their findings indicate that while technical challenges persisted from pandemic to war, psychosocial support needs intensified dramatically under wartime conditions.

The issues of organizing the process of education in the conditions of war in Ukraine and Ukrainian refugee children abroad are considered by Nychkalo et al. [40], Ivaniuk [41, 42], Herbst and Sitek [43]. These studies document the fragmentation of educational experiences, with displaced students facing compounded challenges of new educational systems, language barriers, and trauma-related learning difficulties.

The involvement of parents in creating an effective educational environment was researched by Addi-Raccah et al. [44], Goodall [45]. Their pre-war research establishes baseline understanding of parental engagement patterns, providing comparative context for wartime adaptations. Recent studies during crisis contexts, such as Grobler's [46] examination of parental involvement during COVID-19 and Daniela et al. [47] analysis of remote learning perspectives, demonstrate that crisis conditions fundamentally alter traditional engagement patterns.

International experiences provide valuable comparative insights. Research on Syrian refugee education [48] demonstrates the effectiveness of parent-focused interventions in displacement settings, while studies from Uganda [49] highlight successful blended learning models in resource-constrained environments. These findings suggest that parental support programs integrated with digital platforms can mitigate trauma effects and maintain educational continuity despite severe disruption.

3. Theoretical framework

The study employs an ecological systems approach to understand parental engagement with digital environments during crisis. Following Bronfenbrenner's model as applied by Daniela et al. [47], we examine interactions across multiple system levels: the microsystem (parent-child-technology interactions), mesosystem (home-school digital connections), exosystem (community digital resources), and macrosystem (wartime conditions and cultural values).

Digital inclusion theory, as articulated by Owens et al. [50], provides framework for analyzing access barriers beyond simple connectivity metrics. This perspective examines device adequacy, platform usability, digital literacy, and psychosocial readiness as interconnected dimensions affecting parental engagement capacity.

Resilience theory, applied to educational contexts by Halchenko et al. [15], illuminates adaptive responses to crisis. This framework recognizes parents as active agents mobilizing individual, family, and community resources to maintain children's learning despite extreme adversity.

4. Research method

The goal of the article is to present and analyze the results of a survey conducted among parents as participants of the educational process regarding the use of the digital environment of the secondary school where their child is studying and to present the parents' opinion on how to improve this environment. We used following methods to reveal this goal: analysis, synthesis, generalization and systematization of scientific sources – to determine the theoretical, methodological and applied aspects of the problem of using digital learning environment by participants of the educational process, empirical methods, in particular, questionnaires, surveys to find out the readiness of parents to the use of digital learning environment. The data were analyzed and interpreted using the methods of descriptive statistics and defining categories based on the analysis of answers to open questions.

4.1. Research design and participants

The research design was based on an online survey of parents of students in grades 1–11 via Google Forms. Empirical data was collected from 07.10.2024 to 18.10.2024. 5224 respondents took part in the survey. The age group of respondents is as follows: from 27 to 35 years old – 22.7%, from 35 to 45 years old – 60%, from 45 years old and older – 17.3%. By gender, 95.8% of them are female and 4.2% are male. The geographical coverage of the survey includes all regions of Ukraine.

The predominantly female sample reflects gendered patterns in educational involvement documented across multiple studies [46, 47], though this may limit understanding of paternal engagement patterns. Geographic representation included frontline regions (18%), recently liberated territories (7%), internally displaced persons temporarily residing in other regions (12%), and relatively stable western and central regions (63%).

4.2. Instrument development and validation

The survey instrument was developed through iterative process involving literature review, expert consultation, and pilot testing. Initial items were derived from validated instruments used in previous Ukrainian educational research [32, 25], adapted for wartime context. Five educational technology specialists reviewed items for content validity, suggesting modifications to address crisis-specific concerns.

Pilot testing with 50 parents revealed need for simplified technical language and additional response options reflecting wartime realities (e.g., "unable to access due to occupation " or "disrupted by air raids"). The final instrument contained 42 items across five domains: digital platform awareness and usage, communication patterns, device and connectivity access, parental support activities, and improvement priorities.

5. Research results

The study aimed to achieve the following objectives: to test the diagnostics of the effectiveness of using the digital environment of secondary school by parents; to determine the readiness of parents to use the digital environment of the school; to identify the needs and challenges faced by parents; to find out the parents' assessment of their child's skills in independent learning in distance education; to find out the level of material and technical support in the child's family with a device for distance learning.

5.1. Educational format and security context

Taking into account the martial law in the country and the security situation in different regions of Ukraine, it was determined from the respondents' answers that schools organize the educational process in the following ways: face-to-face format (children attend classes physically) – 32.7%, blended format (for example, children attend classes physically for a week and study remotely for a week) – 34.4%, distance format (all classes are held online) – 32.8%. The availability of shelters and the level of security situation affect the organization of the educational process: 67.2% of respondents indicated that children study in one school shift, and 32.8% of respondents indicated that children study in two shifts.

This distribution reflects the complex security landscape across Ukraine. Analysis by region shows stark differences: frontline oblasts report 78% distance learning adoption, while western regions maintain 61% face-to-face instruction. The blended format, most common in central regions, requires parents to adapt weekly to changing modalities, creating additional organizational burden [51].

5.2. Digital platform awareness and usage

It was important to find out to what extent parents, as participants in the educational process, are aware of what educational platform or information and communication system the school uses to manage the educational process and communicate with parents. Among the most common platforms and systems, respondents mentioned the following: New Knowledge (25%), Single School (14.3%), Human School (11.7%), My Class (8.5%), Eddy (1.4%), My School (0.9%), SMART School (0.1%), and School Today (0.1%). It was found that 34.6% of respondents did not know the answer to this question (figure 1).

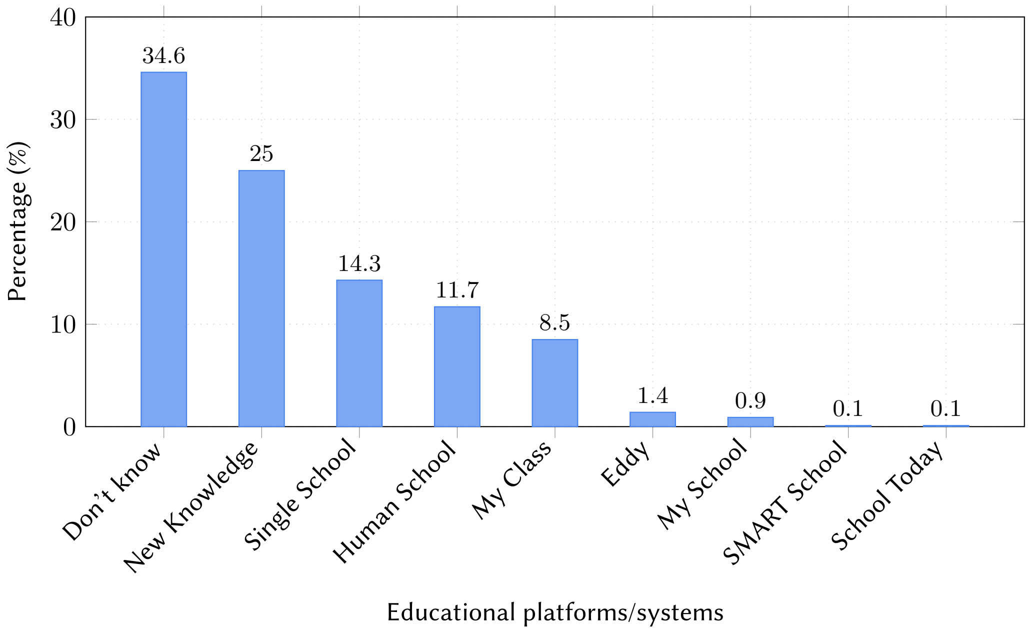

Figure 1: Distribution of respondents' answers to the question 'What educational platform or information and communication system does your school use to manage the educational process and communicate with parents?'.

The finding that 34.6% of parents cannot identify their school's primary platform represents a fundamental disconnect from their children's education. This knowledge gap correlates with several factors: parents with higher education showed 78% awareness versus 52% among those with secondary education; urban parents demonstrated 71% awareness compared to 58% for rural parents; and parents of primary school children showed higher awareness (74%) than parents of senior students (61%).

Given that many schools provide distance and blended learning, it was important to investigate the extent to which parents are aware of the information and communication services used by schools for this purpose. The respondents mentioned the two most common services: Zoom – 59.5% and Google classroom – 43.2%. In addition, respondents pointed out to such services as: Office 365 – 1.4%, Skype – 1.4%, Moodle – 0.5%, Prosvita – 0.5%. It was found that 12.9% of respondents did not know the answer to this question (figure 2).

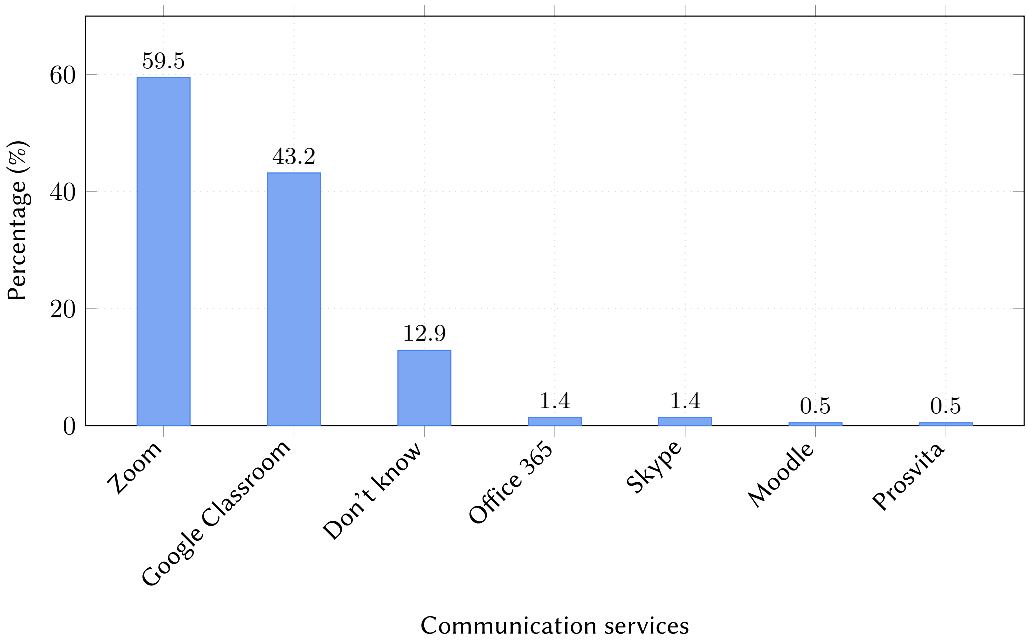

Figure 2: Distribution of respondents' answers to the question 'What information and communication services does your educational institution use to organize distance or blended learning?'.

The higher awareness of communication services (87.1% know their school's platform) compared to learning management systems suggests parents engage more readily with synchronous, familiar tools than specialized educational platforms. This pattern aligns with findings from Khilya et al. [52] on the preference for synchronous over asynchronous learning tools in crisis contexts.

5.3. Electronic journal access and school website usage

Importantly, the vast majority of respondents (80.4%) indicated that they have access to an electronic journal, which suggests that they actively use digital tools and track their children's academic performance. Only 19.6% of respondents said they did not have access to an electronic journal. Among those with access, usage patterns varied: 45% check weekly, 23% check daily, and 32% check rarely. Daily checking correlates with younger children (r = -0.34, $p < 0.001$) and recent displacement (r = 0.28, $p < 0.001$).

School websites help to transform and improve the educational process, as they are part of the information and digital environment. An effective school website represents the institution, reflects the introduction of innovations, provides information support to participants in the educational process, and serves as one of the channels of communication with parents and the public. The overwhelming majority of respondents (69.6%) consider that their school's website contains relevant and useful information for parents, and almost a quarter of respondents (24.8%) said that the information provided is "partially useful" for them. At the same time, 3.2% of respondents gave a negative answer, and 2.4% of respondents said that the website does not work.

Parents indicated the items that the school website contains: links to electronic textbooks and learning materials – 49.4%; feedback – 38.7%; instructions or video guides on how to use the educational platform – 36.6%; advice on psychological support for children – 33.6%; rules of conduct during online classes – 33.2%; rules for safe use of the Internet – 32%; adherence to the principles of academic integrity in the educational process and criteria for assessing students' learning outcomes – 23.2%; none of the above – 12.2%.

The emphasis on psychological support resources (33.6%) reflects wartime realities. Schools providing such resources report higher parental engagement and trust [53]. The relatively low presence of academic integrity information (23.2%) suggests potential gap in addressing digital learning ethics during crisis.

5.4. Communication channels between parents and teachers

An important part of the school's information and digital environment is the channels of communication between parents and teachers. Respondents' answers indicate that parents communicate with their child's class teacher mainly through Viber (93.7%) and Telegram (15.9%). Much fewer of respondents communicate via Facebook messenger (4.3%), WhatsApp (1.2%), Instagram (1.1%), TikTok (0.5%), and Signal (0.2%) (figure 3).

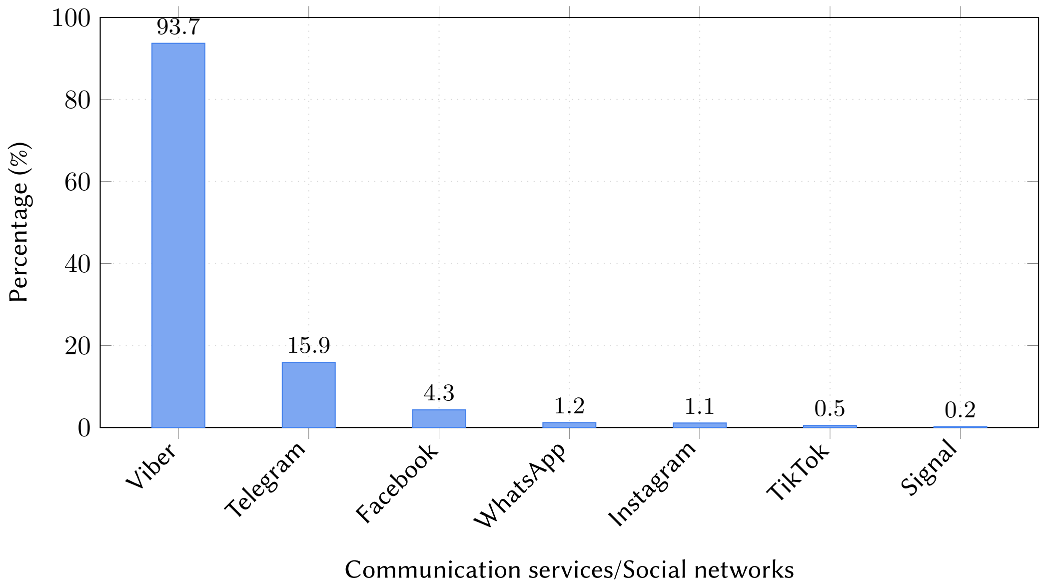

Figure 3: Distribution of respondents' answers to the question 'What communication services or social networks do you use to communicate with your child's class teacher?'.

The overwhelming dominance of Viber reflects pre-war communication patterns that have persisted despite the platform's limitations for educational content sharing. Regional variations exist: Telegram usage reaches 31% in eastern regions where Russian-developed platforms historically had stronger presence. The minimal use of education-specific communication tools suggests missed opportunity for integrated learning support [54].

5.5. Digital skills assessment and device provision

It is important to note that 71.2% of parents highly appreciate the availability of appropriate skills for their child to use digital resources independently in distance learning, which was influenced by the experience of learning during the pandemic and full-scale war. At the same time, 88% of respondents provided their child with a device for distance learning, and 51% of respondents stated that they monitor their child's learning process, which indicates that they provide appropriate support to their child and are involved in the educational process.

However, device provision masks quality disparities. Among device-providing families, 45% report sharing devices among multiple children, 31% describe devices as outdated or inadequate for educational tasks, and 24% rely solely on smartphones. These limitations particularly affect displaced families, where 79% report financial difficulties impacting technology access [55].

Parents' assessment of digital skills reveals generational divide: while 71.2% rate children's skills as good or excellent, only 44.3% express similar confidence in their own abilities. This gap creates stress when technical support is needed, with less digitally confident parents reporting higher anxiety levels when assisting with online learning ($r = 0.42$, $p < 0.001$).

5.6. Qualitative analysis: improvement priorities

It was important to get parents' opinions on how to improve the school's digital environment. The analysis of the responses allowed us to identify eight categories:

1. *Updating material and technical support* (67% of respondents): computers, interactive whiteboards, tablets, generators and uninterrupted power supply, providing access to free and stable Internet for teachers and students. Rural parents particularly emphasized infrastructure challenges, with some reporting daily internet availability under two hours.
2. *Improving the educational process* (52%): conducting additional lessons for students who need help, applying an individual approach to children. Parents of children with special needs particularly emphasized need for differentiated online instruction.
3. *Changing the format of education* (48%): teaching children in face-to-face and blended format, parents do not support distance format because it hinders the socialization of children. However, parents in frontline areas acknowledge distance learning as only viable option despite limitations.
4. *Communication and interaction between participants in the educational process* (41%): feedback from teachers, communication between parents, students and the school administration, regular surveys among parents to improve the educational process.
5. *Use of electronic educational platforms* (38%): introduction of a single platform in the school for organizing the educational process and conducting training on the use of the platform for teachers, students and parents. Platform fragmentation creates particular challenges for families with children in different schools.
6. *Improving the learning process* (33%): using interactive teaching methods and digital learning tools. Parents note that passive video lectures fail to engage children already stressed by war.
7. *Content of websites and social networks* (29%): regular updates on the educational process, using social networks to quickly inform about events and news of the educational institution.
8. *Information security issues* (21%): protection of personal data, implementation of cybersecurity policy in the educational institution, training students and teachers in the basic principles of Internet security. Concerns heightened due to ongoing cyber warfare and targeted attacks on educational infrastructure.

6. Discussion

6.1. The digital divide in wartime education

The finding that 34.6% of parents remain unaware of their school's educational platform reveals deeper structural issues than simple information gaps. This disconnection correlates with multiple vulnerability factors: lower educational attainment, rural residence, displacement status, and linguistic minorities. These parents cannot effectively support their children's learning or advocate for their needs within digital systems [56].

The platform awareness gap intersects with broader digital divides documented across Ukraine. Urban-rural disparities in awareness (71% vs 58%) reflect infrastructure inequalities exacerbated by war. Rural areas face compounded challenges: unreliable electricity, limited internet, and fewer community support resources [57]. These disparities risk creating permanent educational disadvantage for already vulnerable populations.

6.2. Communication infrastructure and parental engagement

The reliance on Viber (93.7%) for educational communication represents both pragmatic adaptation and systemic failure. While Viber enables quick messaging, it lacks educational affordances: assignment submission, resource libraries, progress tracking, or collaborative tools. This forces constant platform-switching, increasing cognitive burden for war-stressed families [58].

Schools' failure to establish unified communication protocols fragments information flow. Parents describe receiving academic updates through Viber, assignments via Google Classroom, announcements on school websites, and emergency notifications through multiple channels. This fragmentation particularly affects displaced families managing multiple children's education while navigating survival needs.

6.3. Psychosocial dimensions of digital learning support

The emphasis on psychological support resources (33.6% seeking such content on school websites) underscores the inseparability of emotional and academic needs during crisis. Current digital environments prioritize content delivery while neglecting psychosocial dimensions, forcing parents into counselor roles without training or support [59].

International interventions provide implementation models. The Hope Groups program demonstrated that structured peer support through digital platforms reduced parental stress by 34% and improved positive parenting behaviors [60]. Ukrainian adaptations like the SEE Learning initiative show promise but reach only 23% of surveyed families, indicating significant unmet need.

6.4. Infrastructure resilience and educational continuity

The 88% device provision rate masks quality disparities that fundamentally affect learning. Families sharing single devices among multiple children cannot maintain synchronous learning schedules. Smartphone-dependent learning (24% of families) limits engagement with complex educational content. These hardware limitations compound with infrastructure instability: power outages, internet disruptions, and air raid interruptions create unpredictable learning environments [61].

Universities' responses to infrastructure attacks provide models for secondary schools. The JetIQ ecosystem demonstrates how distributed systems, backup power, and cached content enable continuity despite attacks [62]. However, implementing such solutions requires resources beyond most secondary schools' capacity, necessitating systematic support.

7. Conclusions and recommendations

The research allowed us to reach the following conclusions. Parents are ready to use the digital environment of their child's school. Most of them know and use educational platforms or information and communication systems of the school, but 36% of respondents are not aware of them and this should be addressed by the school administration to bring such information to parents. It can also be assumed that not all schools have chosen and use such services, in which case local education authorities should work on this issue.

According to most parents, the most critical aspects of improving the school's information and digital environment are updating material and technical support, providing access to the Internet, establishing communication and timely feedback between all participants in the educational process, using a single online educational platform, using interactive methods and digital learning tools, and ensuring information security for students and teachers.

Conducting a regular survey among parents to monitor the effectiveness of the school's information and communication environment is important in order to assess the quality of communication between participants of the educational process, identify problem areas, increase trust and engagement, take into account the needs of educational stakeholders, maintain the effectiveness of the educational process, and introduce innovations that will improve the overall quality of the educational process.

The study's findings have immediate practical implications for Ukrainian education and broader relevance for crisis-affected education globally. The evidence demonstrates that parental engagement in digital environments during crisis requires systematic support across multiple dimensions: infrastructure access, digital competence, psychosocial support, and communication systems.

7.1. Recommendations for schools

Schools should prioritize establishing clear communication hierarchies, designating specific platforms for different functions (academic content, assignments, parent communication, emergency notifications). The current platform fragmentation creates unnecessary barriers for parent engagement. Schools must develop structured onboarding processes ensuring all parents understand and can navigate digital systems, with particular attention to vulnerable populations.

Integration of psychosocial support within learning platforms emerges as critical need. The 33.6% of parents seeking psychological resources indicates significant unmet demand. Schools should embed counseling services, stress management tools, and trauma-informed resources within their digital environments rather than treating these as separate services.

7.2. Recommendations for policymakers

Infrastructure investment must extend beyond individual household connectivity. Community-level solutions – public Wi-Fi points, learning hubs in shelters, mobile connectivity units – can address access gaps more effectively than household-based models. The finding that 79% of displaced families face financial barriers to technology access demands systematic response.

National standardization of educational platforms could reduce training burden and enable resource sharing. While school autonomy has value, the current fragmentation where 34.6% of parents cannot identify their school's platform suggests need for provincial or national coordination. Standardization would particularly benefit mobile populations and families with children in multiple schools.

7.3. Recommendations for community organizations

NGOs and community organizations play critical bridging role between schools and vulnerable families. The success of programs like "School of Responsible Parenting Mediapazly" [54] demonstrates that structured, family-based digital literacy programs yield better outcomes than individual training. Community organizations should prioritize holistic family support recognizing parents' multiple roles: technical supporter, learning coach, emotional counselor, and communication mediator.

7.4. Future research directions

Longitudinal research should track how families develop digital competencies over time and whether initial barriers persist or resolve with experience. The current cross-sectional design captures immediate challenges but cannot reveal adaptation patterns. Studies following families through multiple academic years could identify critical support periods and effective intervention timing.

The pronounced gender skew in respondents (95.8% female) highlights need for targeted research on paternal engagement with digital learning. Understanding how fathers navigate educational support roles could reveal different support needs and engagement strategies.

Research on specific vulnerable populations – families in occupied territories, linguistic minorities, parents with disabilities – remains critical gap. These populations likely face compounded barriers requiring tailored interventions. Developing and validating crisis-appropriate measures of parental digital engagement would enable more precise assessment of intervention effectiveness.

The Ukrainian experience provides crucial evidence for global crisis education response. As conflicts and disasters increasingly disrupt traditional schooling, understanding how families navigate digital learning becomes essential. This research contributes empirical evidence supporting the centrality of parents in crisis education while identifying specific, actionable interventions for strengthening their capacity to support children's learning under extreme adversity. The findings underscore that successful crisis education response must recognize parents not as auxiliary supporters but as essential partners requiring systematic support to fulfill their expanded educational roles.

Declaration on Generative AI

The authors used Scopus AI to find and export in BibTeX the references to strengthen the discussion section, and Claude Opus 4.1 to enhance the writing style.

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