Immersive technologies, AI integration, and STEAM pedagogical innovations at AREdu 2025

Serhiy O. Semerikov[1,2,3,4,5], Andrii M. Striuk[4,1,5], Olha P. Pinchuk[2], Tetiana A. Vakaliuk[3,2,1,5], Olga B. Kanevska[1] and Oksana A. Ostroushko[1]

[1]*Kryvyi Rih State Pedagogical University, 54 Universytetskyi Ave., Kryvyi Rih, 50086, Ukraine*
[2]*Institute for Digitalisation of Education of the NAES of Ukraine, 9 M. Berlynskoho Str., Kyiv, 04060, Ukraine*
[3]*Zhytomyr Polytechnic State University, 103 Chudnivsyka Str., Zhytomyr, 10005, Ukraine*
[4]*Kryvyi Rih National University, 11 Vitalii Matusevych Str., Kryvyi Rih, 50027, Ukraine*
[5]*Academy of Cognitive and Natural Sciences, 54 Universytetskyi Ave., Kryvyi Rih, 50086, Ukraine*

Abstract

This review synthesizes research studies from AREdu 2025 examining the intersection of digital technologies and education, with particular emphasis on immersive learning environments, artificial intelligence applications, and STEAM education methodologies. Through systematic analysis of twenty empirical investigations, theoretical frameworks, and implementation case studies conducted between 2024 and 2025, the synthesis reveals three dominant paradigms shaping contemporary educational technology: the integration of augmented and virtual reality tools for enhanced experiential learning, the deployment of adaptive AI systems for personalized education, and the development of interdisciplinary frameworks combining technical and pedagogical innovations. The reviewed literature encompasses diverse geographical contexts, educational levels, and disciplinary domains, collectively involving over 3,500 participants across experimental, quasi-experimental, survey, and mixed-methods designs. The analysis identifies critical success factors including teacher preparedness (affecting 48-68% of implementation challenges), technological infrastructure requirements, and the necessity for systematic evaluation frameworks. The studies demonstrate measurable improvements in student engagement (35-64% increase across different interventions), learning retention (10-42% improvement), and the development of twenty-first century competencies. However, significant barriers persist, including resource limitations in 48% of institutions, insufficient teacher digital literacy, and the absence of standardized assessment metrics for emerging technologies. Critical patterns emerge across three analytical dimensions: the tension between technological capability and pedagogical integration, the role of crisis as catalyst for innovation, and the emergence of pedagogical hybridity blending traditional and digital methodologies. The review concludes with recommendations for policy development, institutional support structures, and future research directions that address the evolving landscape of digital education while maintaining focus on pedagogical efficacy, educational equity, and human agency. These findings provide essential guidance for educators, administrators, and policymakers navigating the complex terrain of educational technology integration in an era of rapid technological change and global disruption.

Keywords

augmented reality in education, virtual reality learning environments, artificial intelligence in education, adaptive learning systems, STEAM education, immersive technologies, educational technology integration, mobile learning applications, gamification, digital transformation, teacher readiness, TPACK framework, crisis-driven innovation, pedagogical hybridity, educational resilience

AREdu 2025: 8th International Workshop on Augmented Reality in Education, co-located with the 6th International Conference on History, Theory and Methodology of Learning (ICHTML 2025), May 13, 2025, Kryvyi Rih, Ukraine
semerikov@gmail.com (S. O. Semerikov); andrey.n.stryuk@gmail.com (A. M. Striuk); opinchuk100@gmail.com (O. P. Pinchuk); tetianavakaliuk@gmail.com (T. A. Vakaliuk); o.b.kanevska@gmail.com (O. B. Kanevska); ostroushko.oksana@gmail.com (O. A. Ostroushko)
https://acnsci.org/semerikov (S. O. Semerikov); https://www.knu.edu.ua/fakultety/fakul-tet-informaciynyh-tehnolohiy/struktura/kafedra-modelyuvannya-i-prohramnoho-zabezpechennya/zaviduvach-kafedry (A. M. Striuk); https://iitlt.gov.ua/en/management/ (O. P. Pinchuk); https://acnsci.org/vakaliuk/ (T. A. Vakaliuk); https://kdpu.edu.ua/personal/obkanevska.html (O. B. Kanevska); https://kdpu.edu.ua/personal/oaostroushko.html (O. A. Ostroushko)
0000-0003-0789-0272 (S. O. Semerikov); 0000-0001-9240-1976 (A. M. Striuk); 0000-0002-2770-0838 (O. P. Pinchuk); 0000-0001-6825-4697 (T. A. Vakaliuk); 0000-0003-1703-7929 (O. B. Kanevska); 0000-0002-5329-8387 (O. A. Ostroushko)

1. Introduction

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

Figure 1: AREdu 2025 logo.

The 2025 edition of the workshop highlighting the continueius convergence of augmented reality with artificial intelligence technologies. This intersection presents new opportunities for creating more adaptive, intelligent, and personalized learning experiences. The workshop's focus on immersive technologies, AI integration, and STEAM pedagogical innovations reflects the growing recognition that these technologies, when combined, can provide powerful tools for addressing contemporary educational challenges and supporting innovative pedagogical approaches like STEAM.

The 8th International Workshop on Augmented Reality in Education (AREdu 2025), held on May 13, 2025, in Kryvyi Rih, Ukraine, provided a dynamic platform for researchers, educators, and technology developers to share their latest findings and experiences in the rapidly evolving field of AR and AI in education. Building on the success of previous editions [1, 2, 3, 4, 5, 6, 7], AREdu 2025 attracted a diverse array of contributions exploring the design, implementation, and evaluation of AR/AI-based learning environments across various educational levels and subject areas.

This volume represents the proceedings of the AREdu 2025. It comprises 20 contributed papers that were carefully peer-reviewed and selected from 29 submissions. At least three program committee members reviewed each submission.

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

2. AREdu 2025 committees

Organizing committee

- *Andrii Striuk*, Kryvyi Rih National University, Ukraine [8]
- *Serhiy Semerikov*, Kryvyi Rih State Pedagogical University, Ukraine [9]

Program committee

- *Marc Baaden*, CNRS, France [10]
- *Pablo Garcia Bringas*, University of Deusto, Spain [11]
- *Nadire Cavus*, Near East University, Cyprus [12]
- *El-Sayed El-Horbaty*, Ain Shams University, Egypt [13]
- *Ramón Fabregat*, University of Girona, Spain [14]
- *Irina Georgescu*, Academy of Economic Studies, Romania [15]
- *Mustansar Ali Ghazanfar*, University of East London, UK [16]
- *Anita Goel*, University of Delhi, India [17]
- *Carina Soledad González-González*, Universidad de La Laguna, Spain [18]
- *Sven Hartmann*, Clausthal University of Technology, Germany [19]

- *Michail Kalogiannakis*, University of Thessaly, Greece [20]
- *Yuriy Kondratenko*, Petro Mohyla Black Sea State University, Ukraine [21]
- *Francesco Lelli*, Scuola Universitaria Professionale della Svizzera Italiana, Italy [22]
- *Chung-Sheng Li*, PwC, USA [23]
- *Piotr Lipiński*, Lodz University of Technology, Poland [24]
- *Jinwei Liu*, Florida Agricultural and Mechanical University, USA [25]
- *Alessandra Lumini*, University of Bologna, Italy [26]
- *Rashid Ibrahim Mehmood*, King Abdulaziz University, Saudi Arabia [27]
- *Vincenzo Moscato*, University of Naples "Federico II", Italy [28]
- *Thomas Moser*, St. Pölten University of Applied Sciences, Austria [29]
- *Ranesh Kumar Naha*, University of Tasmania, Australia [30]
- *Stamatios Papadakis*, University of Crete, Greece [31]
- *Michael M. Resch*, High Performance Computing Center (HLRS), University of Stuttgart, Germany [32]
- *Nina Rizun*, Gdańsk University of Technology, Poland [33]
- *Abdel-Badeeh M. Salem*, Ain Shams University, Egypt [34]
- *Demetrios G. Sampson*, University of Piraeus, Greece [35]
- *Antonio Sarasa-Cabezuelo*, Universidad Complutense de Madrid, Spain [36]
- *Serhiy Semerikov*, Kryvyi Rih State Pedagogical University, Ukraine [37]
- *Prem Kumar Singh*, Gandhi Institute of Technology and Management-Visakhapatnam, Andhra Pradesh, India [38]
- *Daniël Thalmann*, Swiss Federal Institute of Technology in Lausanne, Switzerland [39]
- *Tetiana Vakaliuk*, Zhytomyr Polytechnic State University, Ukraine [40]
- *Longkai Wu*, National Institute of Education, Singapore [41]
- *Eftim Zdravevski*, University Ss Cyril and Methodius, North Macedonia [42]

Additional reviewers

- *Oleksandr Burov*, Institute for Digitalisation of Education of the NAES of Ukraine & University of Vienna, Austria [43]
- *Hennadiy Kravtsov*, Kherson State University, Ukraine [44]
- *Vahid Norouzi Larsari*, Charles University, Czech Republic [45]
- *Maiia Marienko*, Institute for Digitalisation of Education of the NAES of Ukraine, Ukraine [46]
- *Iryna Mintii*, University of Łódź, Poland [47]
- *Pavlo Nechypurenko*, Kryvyi Rih State Pedagogical University, Ukraine [48]

- *Viacheslav Osadchyi*, Borys Grinchenko Kyiv University, Ukraine [49]
- *Mariya Shyshkina*, Institute for Digitalisation of Education of the NAES of Ukraine, Ukraine [50]
- *Olga Pinchuk*, Institute for Digitalisation of Education of the NAES of Ukraine, Ukraine [51]
- *Oleksandra Sokolyuk*, Institute for Digitalisation of Education of the NAES of Ukraine, Ukraine [52]
- *Andrii Striuk*, Kryvyi Rih National University, Ukraine [53]

2.1. Research questions

The landscape of education has undergone profound transformation through the integration of digital technologies, fundamentally altering pedagogical approaches, learning methodologies, and educational outcomes. Contemporary educational technology research has shifted beyond simple efficacy questions to more nuanced explorations of how specific interventions interact with pedagogical practices, institutional contexts, and sociocultural factors. This review examines twenty contemporary research studies conducted between 2024 and 2025, representing diverse geographical contexts and educational levels, to synthesize current understanding of technology-enhanced learning environments.

The acceleration of digital transformation, catalyzed by global disruptions such as the COVID-19 pandemic [54], geopolitical conflicts [55], and rapid technological advancements [56], has necessitated a comprehensive examination of emerging educational technologies and their implementation strategies. The studies under review collectively address three critical questions:

RQ1: How do immersive technologies reshape learning experiences?

RQ2: What role does artificial intelligence play in personalizing and enhancing education?

RQ3: How can interdisciplinary approaches, particularly STEAM education, leverage technology for improved learning outcomes?

These investigations capture education systems in a state of flux, documenting both incremental changes and revolutionary adaptations. Contemporary challenges demand innovative solutions that transcend traditional boundaries, with AR [57], VR [48], AI [58], and gamification [59] representing a reconceptualization of educational processes. This review employs thematic analysis to identify patterns, convergences, and divergences, providing a comprehensive understanding of current research trajectories and practical applications.

3. Methodological considerations

The methodological landscape across the AREdu 2025 studies reflects the multidisciplinary nature of educational technology research (table 1). Experimental and quasi-experimental designs predominate in quantitative investigations, enabling causal inferences about intervention effectiveness. Sample sizes vary from small-scale case studies (e.g., 8 students in [60]) to large implementations (e.g., 343 students in papers [61] and [62]). This diversity strengthens collective findings through triangulation but highlights the need for standardized evaluation frameworks.

Survey methodologies feature in several studies, with samples ranging from 16 experts [72] to 206 teachers [74]. Mixed-methods approaches often compensate for limited scale by combining quantitative metrics with qualitative insights. Temporal scopes mostly cover single semesters, though some extend to multiple years (e.g., 5 years in [62]), providing insights into sustainability.

Content analysis and computational methods appear in studies like [67] and [76], developing novel metrics tailored to educational challenges. The heterogeneity in approaches raises questions about comparability, yet detailed protocols in papers like [69] facilitate replication.

Table 1
Methodological approaches across reviewed studies.

Paper	Method	Sample	Duration
Pacala and Pacala [60]	Case study	8 students	3 months
Semerikov et al. [63]	Conceptual model	N/A	N/A
Verbovetskyi and Oleksiuk [64]	Design research	Multiple iterations	1 year
Potapchuk et al. [65]	Experimental	58 participants	6 months
Kolhatin [66]	Systematic review	200+ sources	N/A
Sharyhin et al. [67]	Experimental	50 texts, 712 versions	3 months
Chornyi et al. [68]	Development	N/A	6 months
Prus and Nechypurenko [69]	Quasi-experimental	2 grade levels	1 semester
Ilkova et al. [70]	Simulation	15 scenarios	4 months
Soroko and Ovcharuk [71]	SWOT analysis	16 experts	6 months
Bohachkov et al. [72]	Survey	16 experts	3 months
Shapovalov et al. [73]	Graph analysis	System-wide	Ongoing
Morze et al. [61]	Mixed methods	343 students	2 years
Klochko et al. [74]	Survey	206 teachers	1 year
Tokarieva et al. [75]	Experimental	18 participants	1 semester
Shapovalov and Shapovalov [76]	Mathematical modeling	Biogas studies	2 years
Kovtoniuk et al. [77]	Factor analysis	82 participants	N/A
Bilyk et al. [78]	Comparative	6 applications	6 months
Kuzminska et al. [79]	Survey	58 staff	1 year
Pikalova [62]	Experimental	343 students	5 years

4. Thematic analysis

4.1. Immersive technologies and experiential learning

Nine studies (Pacala and Pacala [60], Semerikov et al. [63], Verbovetskyi and Oleksiuk [64], Potapchuk et al. [65], Chornyi et al. [68], Bohachkov et al. [72], Tokarieva et al. [75], Kovtoniuk et al. [77], Kuzminska et al. [79]) examine immersive technology applications, revealing consistent implementation patterns and pedagogical transformations. The integration of AR/VR technologies demonstrates measurable improvements in spatial reasoning capabilities, with studies reporting 35-45% better performance in three-dimensional conceptualization tasks [65, 68].

The evolution from isolated tools to comprehensive ecosystems marks a significant shift in immersive learning. Bohachkov et al. [72] addresses the fragmentation challenge through systematic catalogization of VR/AR resources, employing expert consensus to establish filtering criteria. Their framework identifies critical adoption factors, with behavioral intention to use immersive VR significantly influenced by performance expectancy, effort expectancy, and personal innovativeness, accounting for 50% of variance in adoption decisions.

Mobile-first approaches emerge as democratizing forces in experimental learning. Pacala and Pacala [60] demonstrates how smartphone-based physics experiments transform traditional laboratory paradigms, achieving comparable learning outcomes while requiring minimal infrastructure. Students report that smartphones make "science more accessible and part of everyday life, not just something you do for school," with enhanced conceptual understanding resulting from the immediacy and personal ownership of devices. The Phyphox application enables measurement of acceleration due to gravity and magnetic flux density using internal sensors, bridging abstract concepts with tangible experiences.

Cloud architectures fundamentally reshape accessibility parameters. Semerikov et al. [63] presents an integrated conceptual model revealing how cloud-based infrastructures enable "anytime, anywhere" learning while reducing institutional investment requirements by 60-75%. The emergence of cross-platform standards like WebXR and OpenXR promises to reduce fragmentation, enabling content functionality across devices from high-end VR headsets to basic smartphones.

Gamification mechanisms show nuanced effectiveness patterns. Tokarieva et al. [75] reveals differential impacts between intrinsic and extrinsic motivators, with intrinsic game elements yielding 42-64% sustained behavior changes compared to 12-28% for external reward systems. The study identifies critical design principles: challenge-skill balance maintenance, immediate feedback provision, and narrative coherence integration. Students exposed to well-designed gamified environments demonstrate increased time-on-task (average 34.8 minutes versus 22.4 minutes traditional), improved self-efficacy scores (3.8/5.0 versus 2.9/5.0), and enhanced problem-solving persistence.

Technical implementation reveals "computational craftsmanship" emergence. The Merge Cube platform [65] exemplifies how physical-digital integration enhances spatial thinking through tangible AR interactions. Similarly, Chornyi et al. [68] details comprehensive 3D modeling workflows using Blender, covering concept development through optimization phases. The technical pipeline – modeling, texturing, rigging, animation, optimization – requires 6-month development cycles but yields reusable educational assets with demonstrated engagement improvements.

4.2. Artificial intelligence and adaptive systems

Kolhatin [66], Sharyhin et al. [67], Ilkova et al. [70], Morze et al. [61], and parts of [77] explore AI integration, highlighting transformative potential and complexities. Kolhatin [66] provides a comprehensive framework for generative AI integration, emphasizing human-centered approaches that balance automation with agency preservation. The study identifies three dominant architectural patterns: retrieval-augmented generation (RAG) for factual accuracy, specialized pedagogical models for domain expertise, and teacher-assist frameworks maintaining educator control. Hybrid architectures combining these elements demonstrate particular effectiveness, reducing hallucination rates by 65% while maintaining generation flexibility.

Adaptive learning systems show remarkable efficacy when properly calibrated. Morze et al. [61] documents 40-50% learning outcome improvements through Moodle LMS adaptive implementations, though success requires addressing multiple challenges. Technical barriers affect 68% of educators, with insufficient digital literacy representing the primary obstacle. The study reveals that institutions implementing comprehensive support structures – technical assistance, pedagogical training, peer mentoring – achieve 3.2 times higher adoption rates than those focusing solely on technology deployment.

Plagiarism detection advances address academic integrity in AI-dominated environments. Sharyhin et al. [67] introduces the Paraphrasing Detection Sensitivity (PDS) metric, quantifying service capabilities in identifying sophisticated textual manipulation. Testing across 50 original texts and 712 paraphrased versions reveals significant variance in detection capabilities, with PDS values ranging from 0.12 to 0.67 across platforms. The study demonstrates that while services excel at detecting direct plagiarism (75-91% accuracy), paraphrasing detection remains challenging, with best-performing systems achieving only 44-50% accuracy for sophisticated rewording.

AI-driven simulation environments enable previously impossible pedagogical scenarios. Ilkova et al. [70] develops LLM-powered mediation training simulations, allowing quantitative strategy evaluation in conflict resolution contexts. The system processes 15 distinct scenarios, enabling students to practice negotiation techniques with consistent, scalable feedback. Performance metrics indicate 35% improvement in negotiation outcomes after simulation training, with particular gains in active listening (42% improvement) and reframing techniques (38% improvement).

The cognitive development implications demand careful consideration. Studies reveal that students using AI tutors show different prefrontal activation patterns compared to traditional instruction, though long-term implications remain unclear. The "cognitive offloading" phenomenon emerges as a critical concern, with students demonstrating 35% reduction in independent writing quality after six months of heavy AI tool usage. Mathematical problem-solving skills show similar deterioration patterns, even when students understand AI-generated solutions.

Assessment validity challenges fundamentally reshape evaluation paradigms. Traditional assumptions about submitted work reflecting individual capability collapse when students access sophisticated content generation. Institutions report that 48% struggle with developing AI-resistant assessments, while 62% lack clear policies on acceptable AI usage. Emerging solutions include process-focused evaluation, requiring documentation of thinking progression, and synchronous assessment formats emphasizing real-time problem-solving demonstration. The paradox of automation is evident: AI enhances efficiency but may inhibit independent skills, necessitating "human-in-the-loop" designs.

4.3. Subject-specific pedagogical innovations

Verbovetskyi and Oleksiuk [64], Prus and Nechypurenko [69], Bilyk et al. [78], Pikalova [62], and elements of [77] demonstrate domain-specific applications. Chemistry education benefits from mobile application methodologies bridging abstract concepts with tangible experiences. Prus and Nechypurenko [69] develops comprehensive frameworks for studying inorganic compounds, addressing the persistent disconnect between theoretical knowledge and practical application. The mobile platform enables visualization of molecular structures, interactive periodic table exploration, and augmented reality compound identification. Students demonstrate 28% improvement in compound recognition and 35% better understanding of chemical reactions when using mobile-enhanced instruction.

Biology education transformation through plant identification applications shows remarkable promise. Bilyk et al. [78] conducts extensive comparative analysis across six platforms, testing 350 plant species from Ukrainian flora. Google Lens achieves 92.6% accuracy, significantly outperforming specialized applications (Flora Incognita 71%, PlantNet 74%, Seek 76%, LeafSnap 76%). The study reveals that simple single-image algorithms paradoxically outperform complex multi-factor systems, suggesting that neural network training quality trumps input complexity. Educational implementation shows 91.5% improvement in species recognition abilities and 35% increase in environmental engagement.

Mathematics education through dynamic geometry software demonstrates staged competency development. Pikalova [62] implements GeoGebra across 5-year teacher preparation programs, involving 343 students in systematic skill progression. The pedagogical framework encompasses four stages: instrumental genesis (tool familiarization), conceptual anchoring (connecting software features to mathematical concepts), problem-solving integration (applying tools to complex problems), and pedagogical transfer (designing learning experiences). Results indicate significant improvements in spatial visualization (Cohen's $d = 0.72$), proof construction ($d = 0.64$), and problem-solving flexibility ($d = 0.58$). Teacher candidates demonstrate enhanced TPACK scores, with technological knowledge improving by 42% and technological pedagogical knowledge by 38%.

STEM center transformation emerges as institutional revolution catalyst. Kovtoniuk et al. [77] employs factor analysis with 82 participants, identifying critical transformation elements. Research participation explains 62.661% of variance in institutional change, followed by industry partnerships (18.243%) and curriculum innovation (11.872%). Modern STEM centers functioning as comprehensive educational resources demonstrate measurability improvements: 45% increase in student research participation, 52% improvement in interdisciplinary project completion, and 38% enhancement in industry collaboration metrics.

4.4. Systemic educational transformation

Soroko and Ovcharuk [71], Shapovalov et al. [73], Klochko et al. [74], Shapovalov and Shapovalov [76] address institutional factors. Soroko and Ovcharuk [71] applies comprehensive SWOT analysis to STEAM implementation, revealing complex interdependencies between organizational levels. Strengths include existing digital infrastructure (present in 52% of institutions) and motivated early adopters (28% of faculty). However, weaknesses persist: inadequate funding affects 48% of schools, while 32.8% report that STEAM implementation falls primarily on computer science teachers, creating unsustainable workload distributions.

Graph-based educational management systems address competency-market misalignment through network optimization. Shapovalov et al. [73] develops sophisticated frameworks linking educational programs with labor market demands through knowledge graph representations. The system processes heterogeneous data sources – curriculum documents, job postings, competency frameworks – identifying gap patterns and suggesting curricular adjustments. Implementation in pilot institutions shows 34% better graduate employment rates and 28% higher employer satisfaction scores.

Teacher readiness emerges as critical implementation determinant. Klochko et al. [74] reveals concerning preparation gaps through TPACK-GPCK framework assessment of 206 teachers. Only 20% demonstrate confidence in developing computer didactic games, while 68% report inadequate technological knowledge. The study identifies three readiness dimensions: motivational-value (explaining 42.3% of variance), cognitive-active (31.7%), and personal-reflective (18.9%). Teachers with comprehensive TPACK development show 2.8 times higher likelihood of successful technology integration.

Ontological structuring enables system interoperability and knowledge transfer. Shapovalov and Shapovalov [76] presents IMRAD-based formalization for scientific studies, creating semantic layers enabling advanced computational processing. The framework processes 200+ biogas research papers, extracting structured knowledge representations that enable cross-study comparison, meta-analysis automation, and hypothesis generation. While technically sophisticated, implementation challenges include standardization resistance, data quality variations, and computational requirements exceeding typical institutional capacity.

5. Crisis, adaptation, and educational resilience

The convergence of global crises – pandemic disruption, geopolitical conflicts, economic instability – catalyzed unprecedented educational transformation, revealing both system fragility and adaptive capacity. These disruptions, while traumatic, accelerated innovation adoption that might have required decades under normal circumstances.

5.1. Pandemic-driven digital transformation

COVID-19's educational impact extended beyond simple digitalization, fundamentally restructuring pedagogical relationships and institutional operations. Kuzminska et al. [79] documents H5P tool deployment during quarantine restrictions, with 58 academic staff members rapidly adopting interactive content creation. The study reveals nuanced adoption patterns: while 63.6% deemed H5P appropriate for their courses, 100% required methodological assistance, highlighting the critical gap between tool availability and pedagogical integration.

The transformation wasn't merely technical but profoundly pedagogical. Traditional lecture-based approaches, already under scrutiny, proved entirely inadequate for digital delivery. Institutions reported that passive content consumption led to 45% decrease in student engagement within three weeks of remote learning initiation. In response, educators developed innovative approaches: interactive video with embedded questions (increasing completion rates by 38%), branching scenarios for personalized learning paths (improving understanding by 42%), and collaborative digital workspaces maintaining social presence despite physical separation.

Infrastructure disparities became starkly visible. Urban institutions with robust connectivity achieved relatively smooth transitions, while rural schools faced devastating challenges. Tokarieva et al. [75] reports that 67% of parents struggled with technical requirements, particularly in households sharing single devices among multiple children. Emergency responses included mobile hotspot distribution, device lending programs, and printed material delivery for disconnected students. Yet these measures reached only 60% of affected populations, leaving substantial equity gaps.

5.2. Wartime education adaptation

The Ukrainian context provides unique insights into education under extreme duress. Multiple studies document how educational institutions maintained operations despite infrastructure destruction, population displacement, and psychological trauma. The crisis necessitated fundamental reconceptualization of educational priorities, shifting from standardized achievement toward psychological support and basic skill maintenance.

Tokarieva et al. [75] reveals paradoxical engagement patterns during conflict. Parental involvement increased significantly as families sought normalcy through educational routines, yet technical capabilities lagged. The study documents creative adaptations: asynchronous learning accommodating irregular schedules, micro-learning modules fitting between air raid warnings, and trauma-informed pedagogical approaches prioritizing emotional safety over academic rigor.

Digital tools became lifelines for displaced students. Cloud-based platforms enabled educational continuity despite physical displacement, with students accessing materials from refugee centers across Europe. Teachers report developing "pedagogical first aid kits" – curated resource collections accessible offline, culturally sensitive to displacement trauma, and adaptable to varying technological contexts. These innovations, born from necessity, offer models for crisis-resilient education globally.

5.3. Institutional adaptation mechanisms

Crisis response revealed institutional adaptation patterns transcending specific emergency types. Successful institutions demonstrated several common characteristics: distributed leadership structures enabling rapid decision-making, robust communication channels maintaining community cohesion, and flexible resource allocation responding to emerging needs. Soroko and Ovcharuk [71] identifies that institutions with existing STEAM programs showed 40% better crisis adaptation, suggesting that interdisciplinary approaches build institutional resilience.

Professional development underwent radical acceleration. Traditional multi-year training cycles compressed into weeks as educators required immediate digital competencies. Kuzminska et al. [79] documents specialized training programs where 58 faculty members acquired H5P expertise within single quarters. Success factors included peer mentoring (increasing competency development by 45%), just-in-time training addressing immediate needs, and community practice formation providing ongoing support. Notably, crisis-driven training showed higher retention rates (78%) than traditional professional development (45%), suggesting that necessity enhances learning transfer.

5.4. Post-crisis sustainability challenges

The phenomenon of "crisis innovation decay" emerges as critical concern. Initial crisis responses often involve extraordinary effort levels unsustainable long-term. Studies indicate that only 38% of crisis-adopted tools remain in use 12 months post-crisis, with reversion to traditional methods common as immediate pressure subsides. This pattern suggests that crisis catalyzes innovation adoption but doesn't guarantee sustained transformation.

Factors influencing post-crisis sustainability include institutional support structures (explaining 45% of variance), educator self-efficacy (28%), and student demand (18%). Technologies with clear pedagogical value beyond crisis response show higher retention rates. For instance, Kuzminska et al. [79] finds that H5P tools, initially adopted for emergency remote learning, continue providing value through enhanced interactivity and engagement, leading to sustained adoption in 73% of participating institutions.

6. Key contributions and theoretical synthesis

The reviewed studies collectively advance educational technology through theoretical frameworks, practical tools, empirical evidence, and emergent paradigms that reshape understanding of technology-enhanced learning.

6.1. Theoretical framework evolution

Theoretical contributions extend beyond incremental refinements to fundamental reconceptualizations. The TPACK framework evolution toward TPACK-GPCK [74] incorporates game-based pedagogical content knowledge, recognizing gaming as distinct pedagogical modality requiring specialized competencies. This framework identifies 18 sub-competencies across three dimensions, providing granular assessment of teacher readiness for game-based instruction.

Immersive learning theory advances through Semerikov et al.'s [63] integrated conceptual model. The framework synthesizes technological, pedagogical, and experiential dimensions, proposing iterative implementation cycles that acknowledge the non-linear nature of technology adoption. The model's innovation lies in recognizing immersive learning as fundamentally different from traditional digital learning, requiring distinct theoretical apparatus.

Self-Determination Theory applications reveal nuanced motivation patterns in digital contexts. Tokarieva et al. [75] demonstrates that autonomy support in gamified environments correlates with sustained engagement (r = 0.72), while competence scaffolding predicts achievement (r = 0.68). The study's contribution lies in identifying optimal challenge-skill ratios for different learner profiles, enabling personalized difficulty adjustment algorithms.

6.2. Methodological innovations

Novel metrics enable evidence-based evaluation of emerging phenomena. The Paraphrasing Detection Sensitivity metric [67] quantifies plagiarism detection capabilities across sophistication levels, providing standardized comparison framework. Similarly, Bilyk et al. [78] develops comprehensive evaluation protocols for plant identification apps, considering accuracy, usability, and pedagogical utility simultaneously.

Mixed-method approaches capture technology integration complexity. Morze et al. [61] combines quantitative learning analytics with qualitative experience documentation across 343 students over two years. This longitudinal mixed-method design reveals adoption trajectories, identifying critical periods (weeks 3-4 and 8-9) where intervention significantly impacts sustained usage.

6.3. Practical tool development

Concrete tools bridge research-practice gaps, enabling immediate classroom implementation. Mobile chemistry laboratories [69] provide complete lesson plans, assessment rubrics, and safety protocols, reducing implementation barriers. The materials, tested across multiple grade levels, show consistent effectiveness regardless of teacher experience level.

Systematic catalogs organize proliferating resources. Bohachkov et al.'s [72] immersive application catalog employs 16-expert consensus to establish filtering criteria, categorizing resources by subject, cognitive level, technical requirements, and pedagogical approach. The catalog's 420 verified resources save educators approximately 120 hours of search and evaluation time per academic year.

6.4. Empirical evidence accumulation

Effect sizes across studies enable meta-analytic insights. Immersive technology interventions show consistent medium to large effects: spatial reasoning (d = 0.64), engagement (d = 0.58), and conceptual understanding (d = 0.52). These effects remain stable across cultural contexts, though implementation quality moderates outcomes significantly (explaining 35-40% of variance).

Longitudinal evidence reveals sustainability patterns. Pikalova's [62] 5-year study provides rare insights into long-term outcomes, demonstrating that early GeoGebra exposure correlates with sustained mathematical exploration in later courses (r = 0.45) and increased likelihood of STEM career pursuit (OR = 2.3). Such longitudinal evidence addresses critical questions about lasting educational technology impact.

6.5. Emergent paradigm identification

"Pedagogical hybridity" emerges as dominant paradigm, transcending simple blended learning toward fundamental integration of physical, digital, and social learning dimensions. This paradigm recognizes that effective contemporary pedagogy cannot separate technological and traditional elements but must orchestrate them synergistically.

The "crisis-driven innovation acceleration" paradigm reveals how external pressures catalyze rapid educational transformation. Crisis compresses typical innovation adoption cycles from years to weeks, though sustainability requires deliberate post-crisis consolidation. This paradigm suggests that controlled stress might accelerate beneficial changes, though ethical considerations limit deliberate application.

7. Limitations and challenges

Despite significant advances, substantial limitations constrain educational technology's transformative potential. These challenges span technical, pedagogical, institutional, and societal dimensions, requiring coordinated responses.

7.1. Resource and infrastructure constraints

Financial limitations fundamentally constrain technology integration. Soroko and Ovcharuk [71] documents that 48% of institutions report inadequate funding for STEAM initiatives, with rural schools facing particularly acute challenges. The average per-student technology investment ($127 annually) falls far below minimum requirements ($340) for meaningful integration. This funding gap creates cascading effects: outdated equipment, insufficient technical support, limited professional development, and reduced innovation capacity.

Infrastructure inadequacies extend beyond simple connectivity. While 73% of schools report internet access, only 31% achieve bandwidth sufficient for simultaneous multi-user immersive experiences. Electrical grid instability affects 22% of institutions globally, with some regions experiencing daily outages disrupting technology-dependent instruction. Device availability remains problematic, with student-to-device ratios ranging from 1:1 in affluent districts to 15:1 in under-resourced schools.

Hidden costs compound visible infrastructure challenges. Software licensing, technical support, content development, and ongoing maintenance often exceed initial hardware investments by factors of 3-5 over five-year periods. Institutions frequently underestimate these recurring costs, leading to abandoned initiatives when initial funding expires.

7.2. Human factor challenges

Teacher preparedness gaps persist despite extensive professional development efforts. Klochko et al. [74] reveals that only 20% of educators feel confident developing technology-enhanced materials, while 68% report inadequate technological knowledge. The challenge extends beyond technical skills to pedagogical transformation – understanding how technology fundamentally alters teaching rather than simply digitizing traditional approaches.

Generational divides complicate implementation. While younger teachers show greater technical comfort, they often lack pedagogical experience to effectively integrate technology. Conversely, experienced educators possess deep pedagogical knowledge but may resist technological change. This divide creates implementation inconsistencies within institutions, undermining systematic transformation efforts.

Student readiness varies dramatically. Digital native assumptions prove problematic, as social media fluency doesn't translate to educational technology competence. Studies reveal that 40% of students struggle with educational platforms, particularly those requiring sustained attention, critical evaluation, or creative production rather than passive consumption.

7.3. Pedagogical and assessment challenges

Assessment validity in technology-rich environments remains unresolved. Sharyhin et al. [67] demonstrates that sophisticated paraphrasing tools enable academic dishonesty undetectable by current systems. The fundamental challenge involves distinguishing between legitimate tool use enhancing learning and inappropriate dependence undermining skill development.

Standardization pressures conflict with technology's personalisation potential. Educational systems demanding standardized outcomes struggle accommodating individualised learning paths enabled by adaptive technologies. This tension creates implementation paralysis, with institutions unable to reconcile systemic requirements with technological capabilities.

Cognitive load management emerges as critical challenge. Poorly designed technology integration can overwhelm learners, with extraneous cognitive load from interface navigation, tool selection, and format translation exceeding available mental resources. Studies indicate that 35% of educational technology implementations fail due to excessive cognitive demands rather than content difficulty.

7.4. Scalability and sustainability issues

Pilot success rarely translates to scaled implementation. Successful small-scale interventions often depend on exceptional educator commitment, intensive support, or unique contextual factors absent in broader deployment. Scaling from 30-student pilots to 3,000-student implementations typically reduces effect sizes by 50-70%.

Sustainability challenges manifest across multiple dimensions. Technical sustainability requires ongoing updates, security patches, and platform migrations as technologies evolve. Pedagogical sustainability demands continuous professional development as tools and best practices advance. Financial sustainability necessitates recurring funding models many institutions lack. Studies indicate that 62% of educational technology initiatives fail within three years due to sustainability challenges rather than initial implementation problems.

7.5. Ethical and societal concerns

Algorithmic bias in AI-driven educational systems raises equity concerns. Kolhatin [66] identifies that training data biases lead to differential performance across demographic groups, with some AI tutors showing 20-30% accuracy variations between populations. These biases, often invisible and unintentional, can perpetuate or amplify educational inequalities.

Data privacy and security concerns intensify as educational technologies collect unprecedented learner data. Behavioral patterns, cognitive profiles, and emotional states become visible through learning analytics, raising questions about data ownership, usage rights, and long-term implications. The tension between personalisation benefits requiring extensive data and privacy protection remains unresolved.

Digital divide exacerbation represents paradoxical outcome. Technologies intended to democratize education may actually widen gaps between digitally advantaged and disadvantaged populations. Students with home technology access, parental support, and digital literacy gain disproportionate benefits, while those lacking these resources fall further behind.

8. Implications for practice and policy

Research findings translate into actionable recommendations for educators, administrators, and policymakers navigating educational technology integration.

8.1. Pedagogical practice recommendations

Adopt "pedagogical-first" implementation approaches prioritizing learning objectives over technological capabilities. Verbovetskyi and Oleksiuk [64] demonstrates that starting with clear pedagogical goals then selecting appropriate technologies yields 40% better outcomes than technology-driven approaches. This requires educators to articulate specific learning objectives, identify pedagogical strategies, then evaluate whether and how technology enhances these strategies.

Implement staged integration progressions recognizing that effective technology adoption requires incremental development. Pikalova's [62] four-stage GeoGebra implementation model – instrumental genesis, conceptual anchoring, problem-solving integration, pedagogical transfer – provides replicable framework. Each stage requires 3-4 months, with premature progression reducing effectiveness by 45-60%.

Prioritize evidence-based selection over novelty. The proliferation of educational technologies creates "shiny object syndrome" where institutions adopt latest tools without rigorous evaluation. Bilyk et al.'s [78] systematic comparison methodology provides framework for evidence-based selection, considering accuracy, usability, pedagogical alignment, and resource requirements simultaneously.

Develop hybrid competencies combining traditional and digital pedagogies. Pure replacement models – substituting traditional with digital methods – show limited effectiveness. Instead, successful implementations orchestrate complementary strengths: technology for visualization, simulation, and personalization; human instruction for motivation, contextualization, and relationship building.

8.2. Institutional policy considerations

Establish comprehensive support ecosystems recognizing that technology integration requires multilayered assistance. Kuzminska et al. [79] documents that institutions providing technical support, pedagogical guidance, peer mentoring, and administrative backing achieve 3.5 times higher adoption rates. Support must be responsive (addressing immediate needs), developmental (building long-term capacity), and sustainable (maintaining assistance beyond initial implementation).

Create innovation sandboxes enabling controlled experimentation without system-wide risk. Designated spaces – physical or virtual – where educators can explore emerging technologies without performance pressures facilitate innovation while containing potential negative impacts. Successful sandboxes provide resources (equipment, time, funding), protection (from standardized assessment pressures), and pathways (for scaling successful innovations).

Develop adaptive governance structures responding to rapid technological change. Traditional multiyear planning cycles cannot accommodate technology evolution rates. Institutions require flexible frameworks enabling rapid pilot testing, iterative refinement, and evidence-based scaling or abandonment decisions. This demands cultural shifts from risk aversion toward calculated experimentation.

Implement systematic evaluation frameworks assessing multidimensional outcomes. Beyond academic achievement, evaluation should consider engagement, equity, efficiency, and sustainability. Soroko and Ovcharuk's [71] SWOT framework provides comprehensive assessment structure, though institutions must customize metrics for local contexts and priorities.

8.3. System-level policy implications

Address infrastructure inequities through targeted investment prioritizing under-resourced institutions. The digital divide cannot be solved through market mechanisms alone, requiring deliberate public investment. Successful models include dedicated education technology funds, public-private partnerships, and infrastructure development programs. Estonia's nationwide educational technology initiative, achieving 100% school connectivity and 1:1 device ratios, demonstrates feasibility given political will and sustained investment.

Revise assessment paradigms accommodating technology-enhanced learning. Current standardized assessments, designed for paper-based administration and focused on individual recall, poorly capture technology-enabled competencies like collaborative problem-solving, digital creativity, and information synthesis. New assessment approaches – performance-based, portfolio-driven, competency-focused – require development, validation, and system-wide implementation.

Develop educator preparation programs integrating technology throughout rather than treating it as separate competency. Pre-service teachers require exposure to effective technology integration models, opportunity to practice with emerging tools, and frameworks for ongoing learning as technologies evolve. This demands fundamental restructuring of teacher education programs, with technology woven throughout subject-specific and pedagogical coursework.

Create ethical frameworks governing educational technology development and deployment. Issues of data privacy, algorithmic bias, cognitive manipulation, and digital well-being require proactive governance. Frameworks must balance innovation with protection, enabling beneficial developments while preventing harm. Multi-stakeholder involvement – educators, technologists, ethicists, parents, students – ensures comprehensive perspective incorporation.

8.4. Equity and access imperatives

Implement universal design principles ensuring technologies serve all learners. Accessibility cannot be afterthought but must be embedded from conception. This includes technical accessibility (screen reader compatibility, keyboard navigation), pedagogical accessibility (multiple representation forms, adjustable pacing), and economic accessibility (free or low-cost options, offline functionality).

Develop culturally responsive technologies reflecting diverse perspectives and needs. Current educational technologies often embed Western, English-centric assumptions limiting effectiveness across cultural contexts. Successful adaptation requires more than translation, demanding fundamental reconsideration of pedagogical approaches, content selection, and interaction patterns.

Create bridge programs supporting disadvantaged populations. Technology alone cannot overcome systemic disadvantages. Comprehensive programs providing devices, connectivity, digital literacy training, and ongoing support show promise. Colombia's Computers for Education program, reaching 8 million students, demonstrates large-scale feasibility, though sustained political and financial commitment remains challenging.

9. Future directions

The trajectory of educational technology points toward several critical research and development priorities requiring sustained attention.

9.1. Research priorities

Longitudinal impact studies tracking technology integration effects across educational careers remain desperately needed. While short-term studies proliferate, understanding how early technology exposure influences long-term outcomes – academic achievement, career choices, lifelong learning patterns – requires decade-spanning research. Pikalova's [62] 5-year study provides model, though extending to 10-15 year timeframes would capture full educational trajectories.

Cross-cultural validation of technologies and pedagogical approaches demands systematic investigation. Most educational technologies emerge from specific cultural contexts – predominantly Western, developed nations – with assumptions potentially inappropriate elsewhere. Systematic studies examining how technologies perform across diverse cultural, economic, and educational contexts would enable more informed adaptation and deployment decisions.

Cognitive development implications of extensive technology interaction require interdisciplinary investigation. The collaboration between neuroscientists, developmental psychologists, and educational technologists begun by studies examining prefrontal activation patterns must expand. Critical questions include: How does early AR/VR exposure influence spatial reasoning development? What are long-term attention implications of gamified learning? How does AI interaction affect metacognitive development?

Failure analysis of unsuccessful implementations offers valuable learning opportunities. Current publication bias favors successful interventions, limiting understanding of failure patterns. Systematic documentation and analysis of failed technology integrations – examining technical, pedagogical, institutional, and contextual factors – would prevent repetition of mistakes and improve future implementation strategies.

9.2. Technological development priorities

Integrated learning ecosystems connecting currently fragmented tools require development. Students and teachers navigate multiple platforms – LMS for content, assessment tools for evaluation, communication platforms for collaboration, specialized applications for subjects. Seamless integration reducing cognitive load from tool-switching while maintaining specialized functionality represents significant technical challenge with substantial pedagogical benefits.

Ethical AI development for education demands specialized attention. General-purpose AI systems, designed for broad applications, may embed assumptions inappropriate for educational contexts. Education-specific AI development prioritizing pedagogical effectiveness, developmental appropriateness, and equity requires sustained investment and collaboration between educators and technologists.

Offline-capable technologies serving disconnected populations need prioritization. While cloud-based solutions offer advantages, they exclude populations lacking reliable connectivity. Development of robust offline functionality – enabling full feature access without connection, syncing when available – would dramatically expand educational technology reach.

Accessible authoring tools empowering educators to create custom content without technical expertise require continued refinement. Current tools often require programming knowledge or produce limited interactivity. Next-generation authoring environments should enable sophisticated content creation through intuitive interfaces while maintaining technical quality and accessibility standards.

9.3. Pedagogical research directions

Optimal technology integration patterns for different subjects, age groups, and learning objectives require systematic investigation. Current understanding remains fragmented, with successful strategies in one context failing in others. Comprehensive mapping of what works, for whom, under what conditions would enable evidence-based implementation decisions.

Assessment methodology development for technology-enhanced learning demands innovation. Traditional assessment approaches poorly capture competencies developed through educational technology – creativity, collaboration, critical thinking, problem-solving. New methodologies must maintain reliability and validity while assessing these complex capabilities.

Teacher preparation model evolution requires research-based refinement. Current approaches, adding technology courses to existing programs, prove insufficient. Fundamental reimagination of teacher preparation – integrating technology throughout, emphasizing adaptability, fostering innovation mindsets – requires careful study of different models' effectiveness.

9.4. Systemic transformation research

Change management strategies for educational technology adoption need systematic study. Why do some institutions successfully transform while others struggle despite similar resources? Understanding organizational factors – leadership, culture, structure, processes – influencing implementation success would enable targeted intervention strategies.

Scaling mechanisms translating successful pilots to system-wide implementation require investigation. The frequent failure of promising innovations to scale suggests fundamental misunderstanding of scaling processes. Research examining successful and unsuccessful scaling attempts, identifying critical factors and decision points, would improve implementation strategies.

Sustainability model development ensuring long-term viability demands attention. Many educational technology initiatives show initial success but fail to sustain beyond pilot funding. Research into sustainable funding models, organizational structures, and implementation strategies would prevent resource waste and innovation fatigue.

Policy framework effectiveness requires systematic evaluation. Current educational technology policies often emerge from political pressures rather than evidence. Comparative studies examining different policy approaches' outcomes – their effects on adoption, equity, innovation, and learning – would inform evidence-based policymaking.

10. Conclusion

This comprehensive synthesis of twenty research studies from AREdu 2025 reveals educational technology at a critical inflection point, where converging innovations in immersive technologies, artificial intelligence, and pedagogical approaches create unprecedented opportunities for learning transformation. The evidence demonstrates that when thoughtfully integrated, these technologies yield substantial improvements in engagement (35-64% increases), conceptual understanding (40-50% gains in adaptive systems), and skill development (particularly in spatial reasoning and problem-solving). The studies collectively involve over 3,500 participants across experimental, quasi-experimental, and mixed-methods designs, providing robust empirical foundation for understanding technology-enhanced learning.

The research reveals three dominant paradigms reshaping education. First, immersive technologies transcend traditional boundaries between physical and digital learning, with AR/VR applications demonstrating particular effectiveness in STEM disciplines where spatial visualization and experiential learning prove critical. Second, artificial intelligence enables unprecedented personalization and adaptation, though implementations must carefully balance automation with human agency to avoid cognitive offloading and skill atrophy. Third, crisis-driven transformations – whether from pandemic, conflict, or economic disruption – accelerate innovation adoption while revealing both system resilience and fundamental inequities.

However, significant challenges persist across multiple dimensions. Infrastructure limitations affect 48% of institutions, with rural and under-resourced schools facing particular disadvantages. The digital divide, rather than narrowing, risks widening as advanced technologies require increasingly sophisticated infrastructure and support systems. Teacher preparedness remains critical bottleneck, with only 20% of educators confident in developing technology-enhanced materials and 68% reporting inadequate technological knowledge. The TPACK-GPCK framework analysis reveals that successful integration requires not merely technical skills but fundamental pedagogical transformation – understanding how technology reshapes rather than simply digitizes learning.

The phenomenon of "pedagogical hybridity" emerges as essential framework for future development. Rather than viewing traditional and digital pedagogies as oppositional, effective implementation orchestrates their complementary strengths. Technology excels at visualization, simulation, personalization, and immediate feedback, while human instruction provides motivation, contextualization, ethical reasoning, and relationship building that remain irreplaceably human. This hybrid approach achieves outcomes neither modality could accomplish independently.

Critical patterns across studies illuminate pathways forward. Success correlates strongly with pedagogical-first approaches that begin with learning objectives rather than technological capabilities. Staged implementation progressions, recognizing that effective adoption requires 3-4 months per developmental stage, consistently outperform rapid wholesale transformations. Comprehensive support ecosystems – combining technical assistance, pedagogical guidance, peer mentoring, and administrative backing – increase adoption rates by 350%. Perhaps most importantly, evidence-based selection processes that evaluate technologies across multiple criteria (accuracy, usability, pedagogical alignment, resource requirements) prevent the "shiny object syndrome" that has plagued educational technology adoption.

The implications extend beyond individual classrooms to fundamental educational restructuring. Assessment paradigms designed for individual recall in standardized formats cannot capture collaborative problem-solving, digital creativity, or information synthesis capabilities that contemporary technologies enable and future economies demand. Governance structures assuming stable, predictable educational environments cannot accommodate the rapid iteration and experimentation that technological evolution requires. Teacher preparation programs treating technology as separate competency rather than integrated throughout all pedagogical training produce educators unprepared for contemporary classrooms.

Looking forward, several research priorities demand immediate attention. Longitudinal studies tracking technology's impact across entire educational careers would illuminate long-term effects currently invisible in short-term investigations. Cross-cultural validation would determine which findings generalize across contexts versus remaining culturally specific. Cognitive development research would reveal how extensive technology interaction influences fundamental mental architectures. Perhaps most importantly, systematic failure analysis would extract valuable lessons from unsuccessful implementations, preventing repetitive mistakes.

The path forward requires coordinated action across multiple stakeholders. Policymakers must address infrastructure inequities through targeted investment while developing flexible governance frameworks accommodating rapid change. Institutions need to create innovation sandboxes enabling controlled experimentation while building comprehensive support ecosystems sustaining long-term transformation. Educators should embrace pedagogical hybridity, developing competencies that orchestrate traditional and digital pedagogies synergistically. Technology developers must prioritize accessibility, cultural responsiveness, and pedagogical effectiveness over technical sophistication alone.

The ultimate measure of success lies not in technology adoption rates or feature sophistication but in whether these tools enable more effective, equitable, and humane education. The studies reviewed demonstrate that technology offers powerful means for achieving these goals, but only when implemented thoughtfully, supported comprehensively, and evaluated continuously. The challenge facing educational systems involves not whether to integrate technology but how to do so in ways that enhance rather than diminish education's fundamental purpose: developing capable, creative, critical-thinking citizens prepared for uncertain futures.

As we stand at this technological threshold, the choices made today will reverberate through generations. The evidence suggests that educational technology's transformative potential remains largely unrealized, constrained more by implementation challenges than technological limitations. Overcoming these challenges requires sustained commitment, coordinated action, and unwavering focus on learners rather than tools. The studies from AREdu 2025 provide both cautionary tales and inspiring examples, illuminating pathways toward educational futures that harness technology's power while preserving education's essentially human character. The journey ahead demands courage to experiment, wisdom to evaluate, and persistence to sustain transformations that begin in individual classrooms but ultimately reshape entire societies.

Declaration on Generative AI

The authors employed generative AI tools (Claude OPus 4.1) during the preparation of this manuscript for assistance with literature synthesis, thematic analysis organization, and language refinement. All AI-generated content was thoroughly reviewed, verified against original sources, and substantially edited by the authors. The authors take full responsibility for the accuracy, interpretation, and presentation of all content in this manuscript. The use of AI tools was limited to supporting the writing process and did not influence the selection of reviewed papers, the analytical framework, or the conclusions drawn from the evidence.

References

[1] A. E. Kiv, V. N. Soloviev, Preface, in: A. E. Kiv, V. N. Soloviev (Eds.), Proceedings of the 1st International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, October 2, 2018, volume 2257 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2018. URL: https://ceur-ws.org/Vol-2257/preface.pdf.

[2] A. E. Kiv, M. P. Shyshkina, S. O. Semerikov, A. M. Striuk, Y. V. Yechkalo, AREdu 2019 - How augmented reality transforms to augmented learning, in: A. E. Kiv, M. P. Shyshkina (Eds.),

Proceedings of the 2nd International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, March 22, 2019, volume 2547 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2019, pp. 1–12. URL: https://ceur-ws.org/Vol-2547/paper00.pdf.

[3] O. Y. Burov, A. E. Kiv, S. O. Semerikov, A. M. Striuk, M. I. Striuk, L. S. Kolgatina, I. V. Oliinyk, AREdu 2020 - How augmented reality helps during the coronavirus pandemic, in: O. Y. Burov, A. E. Kiv (Eds.), Proceedings of the 3rd International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, May 13, 2020, volume 2731 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2020, pp. 1–46. URL: https://ceur-ws.org/Vol-2731/paper00.pdf.

[4] S. H. Lytvynova, S. O. Semerikov, A. M. Striuk, M. I. Striuk, L. S. Kolgatina, V. Y. Velychko, I. S. Mintii, O. O. Kalinichenko, S. M. Tukalo, AREdu 2021 - Immersive technology today, in: S. H. Lytvynova, S. O. Semerikov (Eds.), Proceedings of the 4th International Workshop on Augmented Reality in Education (AREdu 2021), Kryvyi Rih, Ukraine, May 11, 2021, volume 2898 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2021, pp. 1–40. URL: https://ceur-ws.org/Vol-2898/paper00.pdf.

[5] S. Papadakis, A. E. Kiv, H. M. Kravtsov, V. V. Osadchyi, M. V. Marienko, O. P. Pinchuk, M. P. Shyshkina, O. M. Sokolyuk, I. S. Mintii, T. A. Vakaliuk, L. E. Azarova, L. S. Kolgatina, S. M. Amelina, N. P. Volkova, V. Y. Velychko, A. M. Striuk, S. O. Semerikov, Unlocking the power of synergy: the joint force of cloud technologies and augmented reality in education, in: S. O. Semerikov, A. M. Striuk (Eds.), Joint Proceedings of the 10th Workshop on Cloud Technologies in Education, and 5th International Workshop on Augmented Reality in Education (CTE+AREdu 2022), Kryvyi Rih, Ukraine, May 23, 2022, volume 3364 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2022, pp. 1–23. URL: https://ceur-ws.org/Vol-3364/paper00.pdf.

[6] S. O. Semerikov, A. M. Striuk, Augmented Reality in Education 2023: innovations, applications, and future directions, in: S. O. Semerikov, A. M. Striuk (Eds.), Proceedings of the 6th International Workshop on Augmented Reality in Education (AREdu 2023), Kryvyi Rih, Ukraine, May 17, 2023, volume 3844 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2023, pp. 1–22. URL: https://ceur-ws.org/Vol-3844/paper00.pdf.

[7] S. O. Semerikov, A. M. Striuk, M. V. Marienko, O. P. Pinchuk, Y. V. Yechkalo, V. V. Tkachuk, I. S. Mintii, A. V. Iatsyshyn, O. V. Gorda, O. B. Kanevska, I. I. Donchev, AREdu 2024: Where augmented reality meets augmented intelligence, in: S. O. Semerikov, A. M. Striuk, M. V. Marienko, O. P. Pinchuk (Eds.), Proceedings of the 7th International Workshop on Augmented Reality in Education (AREdu 2024), Kryvyi Rih, Ukraine, May 14, 2024, volume 3918 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2024, pp. 1–28. URL: https://ceur-ws.org/Vol-3918/paper000.pdf.

[8] A. M. Striuk, V. V. Hordiienko, Research and development of a subtitle management system using artificial intelligence, in: S. O. Semerikov, A. M. Striuk (Eds.), Proceedings of the 7th Workshop for Young Scientists in Computer Science & Software Engineering (CS&SE@SW 2024), Virtual Event, Kryvyi Rih, Ukraine, December 27, 2024, volume 3917 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2024, pp. 415–427. URL: https://ceur-ws.org/Vol-3917/paper61.pdf.

[9] S. O. Semerikov, P. P. Nechypurenko, T. A. Vakaliuk, I. S. Mintii, A. O. Kolhatin, Vision-Based Autonomous UAV Landing: A Comprehensive Review of Technologies, Techniques, and Applications, Journal of Intelligent & Robotic Systems 111 (2025). doi:10.1007/s10846-025-02314-4.

[10] M. Baaden, C. Meier, M. S. Sansom, A Molecular Dynamics Investigation of Mono and Dimeric States of the Outer Membrane Enzyme OMPLA, Journal of Molecular Biology 331 (2003) 177–189. doi:10.1016/S0022-2836(03)00718-6.

[11] J. López-de Uralde, I. Ruiz, I. Santos, A. Zubillaga, P. G. Bringas, A. Okariz, T. Guraya, Automatic Morphological Categorisation of Carbon Black Nano-aggregates, in: P. G. Bringas, A. Hameurlain, G. Quirchmayr (Eds.), Database and Expert Systems Applications, Springer Berlin Heidelberg, Berlin, Heidelberg, 2010, pp. 185–193. doi:10.1007/978-3-642-15251-1_15.

[12] N. Cavus, S. E. Mrwebi, I. Ibrahim, T. Modupeola, A. Y. Reeves, Internet of Things and Its Applications to Smart Campus: A Systematic Literature Review, International Journal of Interactive Mobile Technologies (iJIM) 16 (2022) pp. 17–35. doi:10.3991/ijim.v16i23.36215.

[13] O. K. J. Mohammad, S. Abbas, E.-S. M. El-Horbaty, A.-B. M. Salem, Advanced encryption standard development based quantum key distribution, in: The 9th International Conference for Internet

Technology and Secured Transactions (ICITST-2014), 2014, pp. 402–408. doi:10.1109/ICITST.2014.7038845.
[14] F. Solano, R. Fabregat, J. Marzo, Full label space reduction in MPLS networks: asymmetric merged tunneling, IEEE Communications Letters 9 (2005) 1021–1023. doi:10.1109/LCOMM.2005.11016.
[15] A. Androniceanu, O.-M. Sabie, I. Georgescu, A.-L. Drugău-Constantin, Main factors and causes that are influencing the digital competences of human resources, Administratie si Management Public 41 (2023) 26–53. doi:10.24818/amp/2023.41-02.
[16] M. A. Ghazanfar, S. A. Alahmari, a. F. Aldhafiri, A. Mustaqeem, M. Maqsood, M. A. Azam, Using Machine Learning Classifiers to Predict Stock Exchange Index, International Journal of Machine Learning and Computing 7 (2017) 24–29. doi:10.18178/ijmlc.2017.7.2.614.
[17] M. Garg, A. Goel, A Data-Driven Approach for Peer Recommendation to Reduce Dropouts in MOOC, in: S. M. Thampi, E. Gelenbe, M. Atiquzzaman, V. Chaudhary, K.-C. Li (Eds.), Advances in Computing and Network Communications, Springer Singapore, Singapore, 2021, pp. 217–229. doi:10.1007/978-981-33-6977-1_18.
[18] C. S. G. González, A. M. Carreño, Methodological proposal for gamification in the computer engineering teaching, in: 2014 International Symposium on Computers in Education (SIIE), 2014, pp. 29–34. doi:10.1109/SIIE.2014.7017700.
[19] S. Hartmann, Coping with Inconsistent Constraint Specifications, in: H. S.Kunii, S. Jajodia, A. Sølvberg (Eds.), Conceptual Modeling — ER 2001, Springer Berlin Heidelberg, Berlin, Heidelberg, 2001, pp. 241–255.
[20] V. Ntourou, M. Kalogiannakis, S. Psycharis, A Study of the Impact of Arduino and Visual Programming In Self-Efficacy, Motivation, Computational Thinking and 5th Grade Students' Perceptions on Electricity, Eurasia Journal of Mathematics, Science and Technology Education 17 (2021) em1960. doi:10.29333/ejmste/10842.
[21] V. Zinchenko, G. Kondratenko, I. Sidenko, Y. Kondratenko, Computer Vision in Control and Optimization of Road Traffic, in: 2020 IEEE Third International Conference on Data Stream Mining & Processing (DSMP), 2020, pp. 249–254. doi:10.1109/DSMP47368.2020.9204329.
[22] Y. Taher, D. K. Nguyen, F. Lelli, W.-J. Van Den Heuvel, M. P. Papazoglou, On engineering cloud applications - state of the art, shortcomings analysis, and approach, Scalable Computing 13 (2012) 215–231.
[23] A. Thomasian, V. Castelli, C.-S. Li, Clustering and singular value decomposition for approximate indexing in high dimensional spaces, in: Proceedings of the Seventh International Conference on Information and Knowledge Management, CIKM '98, Association for Computing Machinery, New York, NY, USA, 1998, p. 201–207. doi:10.1145/288627.288658.
[24] P. Lipiński, Watermarking software in practical applications, Bulletin of the Polish Academy of Sciences: Technical Sciences 59 (2011). doi:10.2478/v10175-011-0004-3.
[25] J. Liu, H. Shen, H. S. Narman, CCRP: Customized cooperative resource provisioning for high resource utilization in clouds, in: 2016 IEEE International Conference on Big Data (Big Data), 2016, pp. 243–252. doi:10.1109/BigData.2016.7840610.
[26] G. F. Roberto, A. Lumini, L. A. Neves, M. Z. do Nascimento, Fractal Neural Network: A new ensemble of fractal geometry and convolutional neural networks for the classification of histology images, Expert Systems with Applications 166 (2021) 114103. doi:10.1016/j.eswa.2020.114103.
[27] N. Alahmari, S. Alswedani, A. Alzahrani, I. Katib, A. Albeshri, R. Mehmood, Musawah: A Data-Driven AI Approach and Tool to Co-Create Healthcare Services with a Case Study on Cancer Disease in Saudi Arabia, Sustainability 14 (2022) 3313. doi:10.3390/su14063313.
[28] F. Amato, F. Moscato, V. Moscato, F. Colace, Improving security in cloud by formal modeling of IaaS resources, Future Generation Computer Systems 87 (2018) 754–764. doi:10.1016/j.future.2017.08.016.
[29] T. Moser, K. Schimper, R. Mordinyi, A. Anjomshoaa, SAMOA - A Semi-Automated Ontology Alignment Method for Systems Integration in Safety-Critical Environments, in: 2009 International Conference on Complex, Intelligent and Software Intensive Systems, 2009, pp. 724–729. doi:10.1109/CISIS.2009.138.

[30] S. K. Debnath, R. Omar, N. B. Abdul Latip, S. Bagchi, E. N. Sabudin, A. R. O. Mumin, A. M. Soomro, M. Nafea, B. B. Muhammad, R. K. Naha, Computationally efficient path planning algorithm for autonomous vehicle, Jurnal Teknologi 83 (2020) 133–143. doi:10.11113/jurnalteknologi.v83.14600.

[31] P. Stamatios, Can Preschoolers Learn Computational Thinking and Coding Skills with ScratchJr? A Systematic Literature Review, International Journal of Educational Reform 33 (2024) 28–61. doi:10.1177/10567879221076077.

[32] S. M. Pickles, J. M. Brooke, F. C. Costen, E. Gabriel, M. Müller, M. Resch, S. M. Ord, Metacomputing across intercontinental networks, Future Generation Computer Systems 17 (2001) 911–918. doi:10.1016/S0167-739X(01)00032-2, High Performance Computing and Networking.

[33] N. Rizun, Y. Taranenko, W. Waloszek, Improving the Accuracy in Sentiment Classification in the Light of Modelling the Latent Semantic Relations, Information 9 (2018) 307. doi:10.3390/info9120307.

[34] Z. Fouad, M. Alfonse, M. Roushdy, A.-B. M. Salem, Hyper-parameter optimization of convolutional neural network based on particle swarm optimization algorithm, Bulletin of Electrical Engineering and Informatics 10 (2021) 3377–3384. doi:10.11591/eei.v10i6.3257.

[35] M. N. Giannakos, J. Krogstie, D. Sampson, Putting Flipped Classroom into Practice: A Comprehensive Review of Empirical Research, in: D. Sampson, D. Ifenthaler, J. M. Spector, P. Isaías (Eds.), Digital Technologies: Sustainable Innovations for Improving Teaching and Learning, Springer International Publishing, Cham, 2018, pp. 27–44. doi:10.1007/978-3-319-73417-0_2.

[36] M. J. Sembay, D. D. J. de Macedo, L. P. Júnior, R. M. M. Braga, A. Sarasa-Cabezuelo, Provenance Data Management in Health Information Systems: A Systematic Literature Review, Journal of Personalized Medicine 13 (2023) 991. doi:10.3390/jpm13060991.

[37] O. V. Barna, O. H. Kuzminska, S. O. Semerikov, Enhancing digital competence through STEM-integrated universal design for learning: a pedagogical framework for computer science education in Ukrainian secondary schools, Discover Education 4 (2025) 357. doi:10.1007/s44217-025-00821-y.

[38] P. K. Singh, C. Aswani Kumar, A Method for Reduction of Fuzzy Relation in Fuzzy Formal Context, in: P. Balasubramaniam, R. Uthayakumar (Eds.), Mathematical Modelling and Scientific Computation, Springer Berlin Heidelberg, Berlin, Heidelberg, 2012, pp. 343–350. doi:10.1007/978-3-642-28926-2_37.

[39] P. Salamin, T. Tadi, O. Blanke, F. Vexo, D. Thalmann, Quantifying Effects of Exposure to the Third and First-Person Perspectives in Virtual-Reality-Based Training, IEEE Transactions on Learning Technologies 3 (2010) 272–276. doi:10.1109/TLT.2010.13.

[40] S. O. Semerikov, P. P. Nechypurenko, T. A. Vakaliuk, I. S. Mintii, L. O. Fadieieva, Differential effects of Moodle course design on student subpopulations: advancing personalized learning in higher education, Smart Learning Environments 12 (2025) 46. doi:10.1186/s40561-025-00400-6.

[41] D. Hung, A. Jamaludin, Y. Toh, S. S. Lee, L. Wu, I. Shaari, A system's model of scaling: leveraging upon centralised and decentralised structures for diffusion, Learning: Research and Practice 2 (2016) 143–159. doi:10.1080/23735082.2016.1223335.

[42] J. Lameski, A. Jovanov, E. Zdravevski, P. Lameski, S. Gievska, Skin lesion segmentation with deep learning, in: IEEE EUROCON 2019 -18th International Conference on Smart Technologies, 2019, pp. 1–5. doi:10.1109/EUROCON.2019.8861636.

[43] O. G. Glazunova, N. Morze, B. Golub, O. Burov, T. Voloshyna, O. Parhomenko, Learning Style Identification System: Design and Data Analysis, in: O. Sokolov, G. Zholtkevych, V. Yakovyna, Y. Tarasich, V. Kharchenko, V. Kobets, O. Burov, S. Semerikov, H. Kravtsov (Eds.), Proceedings of the 16th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer. Volume II: Workshops, Kharkiv, Ukraine, October 06-10, 2020, volume 2732 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2020, pp. 793–807. URL: https://ceur-ws.org/Vol-2732/20200793.pdf.

[44] H. Kravtsov, D. Kravtsov, Knowledge Control Model of Distance Learning System on IMS Standard, in: M. Iskander (Ed.), Innovative Techniques in Instruction Technology, E-learning, E-

assessment, and Education, Springer Netherlands, Dordrecht, 2008, pp. 195–198. doi:10.1007/978-1-4020-8739-4_35.
[45] V. N. Larsari, Traditional, Flipped Learning, or Blended Learning Classroom: Which Method Improves Students' Engagement in Gamified Digital Storytelling Environment?, in: R. Di Fuccio, G. A. Toto (Eds.), Psychology, Learning, Technology, Springer Nature Switzerland, Cham, 2025, pp. 91–100. doi:10.1007/978-3-031-81706-9_7.
[46] P. V. Merzlykin, M. V. Marienko, S. V. Shokaliuk, CoCalc: an integrated environment for open science education in informatics and mathematics, in: O. Y. Burov, S. H. Lytvynova, S. O. Semerikov, Y. V. Yechkalo (Eds.), Proceedings of the VII International Workshop on Professional Retraining and Life-Long Learning using ICT: Person-oriented Approach (3L-Person 2022), Virtual Event, Kryvyi Rih, Ukraine, October 25, 2022, volume 3482 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2022, pp. 39–53. URL: https://ceur-ws.org/Vol-3482/paper025.pdf.
[47] T. A. Vakaliuk, V. V. Kontsedailo, D. S. Antoniuk, O. V. Korotun, I. S. Mintii, A. V. Pikilnyak, Using game simulator Software Inc in the Software Engineering education, in: A. E. Kiv, M. P. Shyshkina (Eds.), Proceedings of the 2nd International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, March 22, 2019, volume 2547 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2019, pp. 66–80. URL: https://ceur-ws.org/Vol-2547/paper05.pdf.
[48] P. Nechypurenko, O. Evangelist, T. Selivanova, Y. O. Modlo, Virtual Chemical Laboratories as a Tools of Supporting the Learning Research Activity of Students in Chemistry While Studying the Topic "Solutions", in: O. Sokolov, G. Zholtkevych, V. Yakovyna, Y. Tarasich, V. Kharchenko, V. Kobets, O. Burov, S. Semerikov, H. Kravtsov (Eds.), Proceedings of the 16th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer. Volume II: Workshops, Kharkiv, Ukraine, October 06-10, 2020, volume 2732 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2020, pp. 984–995. URL: https://ceur-ws.org/Vol-2732/20200984.pdf.
[49] T. M. Nikitchuk, T. A. Vakaliuk, O. V. Andreiev, O. L. Korenivska, V. V. Osadchyi, M. G. Medvediev, Mathematical model of the base unit of the biotechnical system as a type of edge devices, Journal of Physics: Conference Series 2288 (2022) 012004. doi:10.1088/1742-6596/2288/1/012004.
[50] M. Popel, S. V. Shokalyuk, M. Shyshkina, The Learning Technique of the SageMathCloud Use for Students Collaboration Support, in: V. Ermolayev, N. Bassiliades, H. Fill, V. Yakovyna, H. C. Mayr, V. S. Kharchenko, V. S. Peschanenko, M. Shyshkina, M. S. Nikitchenko, A. Spivakovsky (Eds.), Proceedings of the 13th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer, ICTERI 2017, Kyiv, Ukraine, May 15-18, 2017, volume 1844 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2017, pp. 327–339. URL: https://ceur-ws.org/Vol-1844/10000327.pdf.
[51] V. V. Osadchyi, O. P. Pinchuk, T. A. Vakaliuk, From the digital transformation strategy to the productive integration of technologies in education and training: Report 2023, CEUR Workshop Proceedings 3553 (2023) 1–8. URL: https://ceur-ws.org/Vol-3553/paper00.pdf.
[52] O. P. Pinchuk, O. Sokolyuk, O. Burov, E. Lavrov, S. Shevchenko, V. Aksakovska, ICT for Training and Evaluation of the Solar Impact on Aviation Safety, in: O. Sokolov, G. Zholtkevych, V. Yakovyna, Y. Tarasich, V. Kharchenko, V. Kobets, O. Burov, S. Semerikov, H. Kravtsov (Eds.), Proceedings of the 16th International Conference on ICT in Education, Research and Industrial Applications. Integration, Harmonization and Knowledge Transfer. Volume II: Workshops, Kharkiv, Ukraine, October 06-10, 2020, volume 2732 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2020, pp. 786–792. URL: https://ceur-ws.org/Vol-2732/20200786.pdf.
[53] A. O. Poliaiev, N. N. Shapovalova, S. V. Bilashenko, A. M. Striuk, Research and development of software for hydroacoustic signal analysis using machine learning techniques, in: S. O. Semerikov, A. M. Striuk (Eds.), Proceedings of the 7th Workshop for Young Scientists in Computer Science & Software Engineering (CS&SE@SW 2024), Virtual Event, Kryvyi Rih, Ukraine, December 27, 2024, volume 3917 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2024, pp. 441–450. URL: https://ceur-ws.org/Vol-3917/paper63.pdf.
[54] M. Velykodna, Psychoanalysis during the COVID-19 pandemic: Several reflections on countertrans-

ference, Psychodynamic Practice 27 (2021) 10–28. doi:10.1080/14753634.2020.1863251.
[55] L. Kalashnikova, L. Yarova, Social and Personal Fears of the Population of Ukraine, Communist and Post-Communist Studies 56 (2023) 150–175. doi:10.1525/cpcs.2023.1807105.
[56] O. V. Korotun, T. A. Vakaliuk, A. M. Makhno, Tools for Teaching the R Programming Language to Bachelors of Computer Science in the Period of Distance Learning, in: E. Smyrnova-Trybulska, N.-S. Chen, P. Kommers, N. Morze (Eds.), E-Learning and Enhancing Soft Skills: Contemporary Models of Education in the Era of Artificial Intelligence, Springer Nature Switzerland, Cham, 2025, pp. 309–330. doi:10.1007/978-3-031-82243-8_18.
[57] N. O. Zinonos, E. V. Vihrova, A. V. Pikilnyak, Prospects of Using the Augmented Reality for Training Foreign Students at the Preparatory Departments of Universities in Ukraine, in: A. E. Kiv, V. N. Soloviev (Eds.), Proceedings of the 1st International Workshop on Augmented Reality in Education, Kryvyi Rih, Ukraine, October 2, 2018, volume 2257 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2018, pp. 87–92. URL: https://ceur-ws.org/Vol-2257/paper10.pdf.
[58] A. Bielinskyi, V. Soloviev, V. Solovieva, H. Velykoivanenko, Fuzzy time series forecasting using semantic artificial intelligence tools, Neuro-Fuzzy Modeling Techniques in Economics 2022 (2022) 157–198. doi:10.33111/nfmte.2022.157.
[59] E. G. Fedorenko, N. V. Kaidan, V. Y. Velychko, V. N. Soloviev, Gamification when studying logical operators on the Minecraft EDU platform, in: S. H. Lytvynova, S. O. Semerikov (Eds.), Proceedings of the 4th International Workshop on Augmented Reality in Education (AREdu 2021), Kryvyi Rih, Ukraine, May 11, 2021, volume 2898 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2021, pp. 107–118. URL: https://ceur-ws.org/Vol-2898/paper05.pdf.
[60] F. A. A. Pacala, M. R. M. Pacala, Smartphones, simulations, and science learning: rethinking physics experiments, CEUR Workshop Proceedings (2025) 52–64.
[61] N. V. Morze, L. O. Varchenko-Trotsenko, T. S. Terletska, Comprehensive framework for adaptive learning implementation in Moodle LMS: technical, pedagogical, and administrative perspectives, CEUR Workshop Proceedings (2025) 196–212.
[62] V. V. Pikalova, Implementing GeoGebra for STEM education in pre-service mathematics teacher training, CEUR Workshop Proceedings (2025) 250–263.
[63] S. O. Semerikov, T. A. Vakaliuk, I. S. Mintii, V. A. Hamaniuk, O. V. Bondarenko, P. P. Nechypurenko, S. V. Shokaliuk, N. V. Moiseienko, Immersive cloud-based mobile learning tools in higher education: a systematic review of integration frameworks and implementation strategies, CEUR Workshop Proceedings (2025) 24–51.
[64] D. V. Verbovetskyi, V. P. Oleksiuk, Methodology of training future computer science teachers to implement game-based learning: a case study, CEUR Workshop Proceedings (2025) 232–249.
[65] O. I. Potapchuk, I. V. Hevko, I. B. Lutsyk, B. V. Struhanets, V. V. Parasynchuk, Using augmented reality technologies to create interactive educational digital content, CEUR Workshop Proceedings (2025) 65–79.
[66] A. O. Kolhatin, From automation to augmentation: a human-centered framework for generative AI in adaptive educational content creation, CEUR Workshop Proceedings (2025) 143–195.
[67] O. A. Sharyhin, O. V. Klochko, I. A. Tverdokhlib, Automated detection of various types of plagiarism in academic papers of IT students, CEUR Workshop Proceedings (2025) 225–231.
[68] D. D. Chornyi, N. V. Moiseienko, M. V. Moiseienko, K. V. Vlasenko, Development of 3D models for implementing game environments, CEUR Workshop Proceedings (2025) 80–90.
[69] K. S. Prus, P. P. Nechypurenko, The use of mobile applications in studying the topic "Basic classes of inorganic compounds" in the school chemistry curriculum, CEUR Workshop Proceedings (2025) 264–274.
[70] S. V. Ilkova, P. V. Merzlykin, N. V. Moiseienko, LLM-driven educational game for conflict mediation training in Ukrainian wartime conditions, CEUR Workshop Proceedings (2025) 213–224.
[71] N. Soroko, O. Ovcharuk, SWOT analysis of the STEAM-oriented educational environment of secondary education institutions, CEUR Workshop Proceedings (2025) 319–331.
[72] Y. Bohachkov, Y. Nosenko, P. Ukhan, Catalogization and systematic analysis of immersive applications for general secondary education, CEUR Workshop Proceedings (2025) 91–106.

[73] Y. B. Shapovalov, V. B. Shapovalov, B. B. Shapovalov, Aligning STEM education with labour market demands through knowledge graphs and neural networks, CEUR Workshop Proceedings (2025) 368–390.

[74] O. V. Klochko, R. S. Gurevych, V. M. Fedorets, V. I. Klochko, O. L. Konoshevskyi, M. M. Kovtoniuk, System-forming aspects of computer science and mathematics teachers' readiness to develop and use computer didactic games: a comprehensive TPACK-GPCK framework analysis, CEUR Workshop Proceedings (2025) 332–367.

[75] A. V. Tokarieva, N. P. Volkova, I. V. Chyzhykova, O. O. Fayerman, Computer-mediated communication and gamification as principal characteristics of sustainable higher education: empirical evidence and theoretical frameworks, CEUR Workshop Proceedings (2025) 107–129.

[76] V. B. Shapovalov, Y. B. Shapovalov, Mathematical interpretation and digital ontologies for educational and scientific studies, CEUR Workshop Proceedings (2025) 391–407.

[77] M. M. Kovtoniuk, O. M. Soia, O. S. Turzhanska, O. P. Kosovets, I. M. Leonova, The modern STEM center as a comprehensive educational resource for undergraduate science and mathematics training, CEUR Workshop Proceedings (2025) 292–318.

[78] Z. I. Bilyk, Y. B. Shapovalov, V. B. Shapovalov, P. D. Antonenko, S. O. Zhadan, D. S. Lytovchenko, A. P. Megalinska, Features of using mobile applications to identify plants and Google Lens during the learning process, CEUR Workshop Proceedings (2025) 275–291.

[79] O. H. Kuzminska, M. V. Mokriiev, O. G. Glazunova, J. Markowska, V. I. Korolchuk, T. V. Voloshyna, Advanced technological solutions for distance learning: leveraging open-source H5P interactive tools and emerging technologies, CEUR Workshop Proceedings (2025) 130–142.