Augmented Reality in Education 2023: innovations, applications, and future directions

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Abstract

The 6th International Workshop on Augmented Reality in Education (AREdu 2023) brought together researchers and practitioners to explore the latest innovations and applications of AR technologies in educational contexts. This paper presents an overview of the workshop's proceedings, comprising 13 peer-reviewed papers spanning diverse areas. Key themes include the integration of AR with other emerging technologies like AI and VR, the design of immersive learning environments, and the evaluation of AR's impact on learning outcomes and motivation. Despite the challenges posed by the ongoing war in Ukraine, AREdu 2023's hybrid format enabled global participation and knowledge sharing. The papers collectively demonstrate AR's potential to transform education and provide valuable insights to guide future research and implementation efforts.

Keywords

augmented reality, educational technology, immersive learning, STEM education, teacher training, virtual environments, empirical studies

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 2023 logo.

The 6th International Workshop on Augmented Reality in Education (AREdu 2023), held on May 17, 2023, 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 in education. Building on the success of previous editions [1, 2, 3, 4, 5, 6], AREdu 2023 attracted a diverse array of contributions exploring the design, implementation, and evaluation of AR-based learning environments across various educational levels and subject areas.

AREdu topics of interest since 2018:

- Virtualization of learning: principles, technologies, tools
- Augmented reality gamification
- Design and implementation of augmented reality learning environments
- Augmented reality in science education
- Augmented reality in professional training and retraining

This volume represents the proceedings of the AREdu 2023. It comprises 13 contributed papers that were carefully peer-reviewed and selected from 17 submissions. At least three program committee members reviewed each submission.

AREdu 2023: 6th International Workshop on Augmented Reality in Education, May 17, 2023, Kryvyi Rih, Ukraine
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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 2023 committees

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3. Proceedings overview

3.1. Virtualization of learning: principles, technologies, tools

The paper "Using native virtualization technologies for teaching IP telephony to future IT specialists" by Pavlenko and Pavlenko [44] explores the application of virtualization technologies for teaching IP telephony to future IT specialists. The effective training of these students requires the development of competencies in installing, operating and maintaining various operating systems and IP telephony software in both local and global network environments. One potential solution to address the challenges of providing such training is the introduction of virtualization technology in the educational process.

The paper reviews different types of virtualization approaches, including full emulation, paravirtualization, native virtualization, operating system-level virtualization, and application-level virtualization. It concludes that native virtualization is the most suitable for creating a virtual training laboratory for IP telephony, as it allows running multiple guest operating systems designed for the same architecture as the host, simulating a computer network with IP telephony servers and clients on a single personal computer.

The study then compares three popular native virtualization solutions—VMware Workstation, Parallels Workstation, and VirtualBox—in terms of their features, supported operating systems, network adapters, licensing costs, etc. Based on this analysis, VirtualBox is identified as the optimal tool for developing a network lab for training future IT professionals in IP telephony, given its support for multiple operating systems, ability to connect up to 36 network adapters to a virtual machine, and free distribution.

Using VirtualBox, a repository of virtual machines was created to support a series of laboratory works on topics such as installing Asterisk and Free PBX, configuring IP telephony servers, setting up dial plans, managing calls, integrating voice services and menus, etc. The virtual laboratory includes server hosts running Ubuntu and Asterisk Free PBX and client hosts running Windows and Linux with IP telephony software like Linphone Desktop (figure 2). This setup enables students to simulate the interaction of server hosts on the Internet and test IP telephony features on user devices.

To evaluate the effectiveness of the proposed virtualization-based training approach, a pedagogical

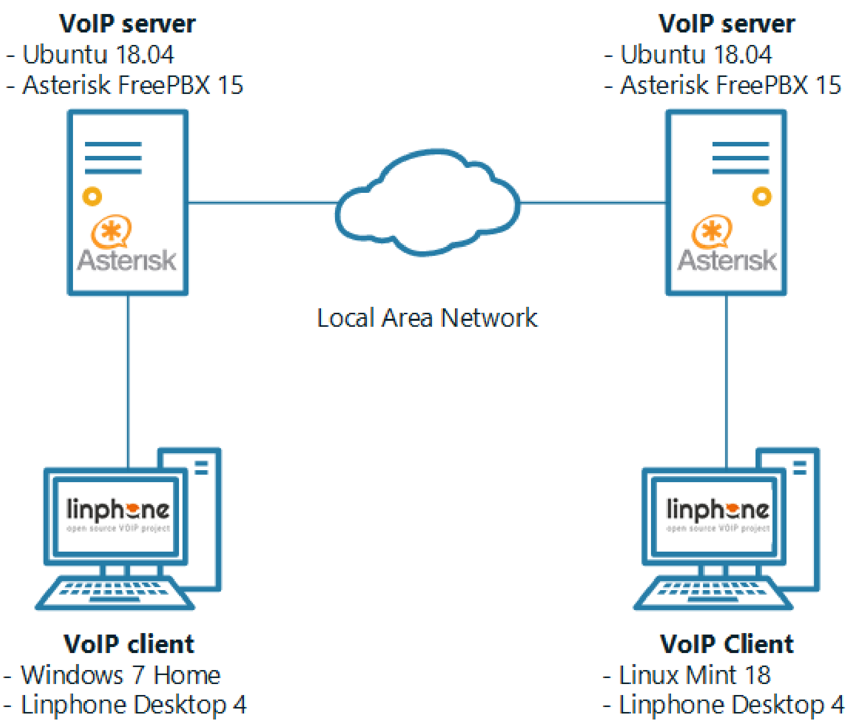

Figure 2: Virtual laboratory of IP telephony [44].

experiment was conducted involving control and experimental groups of students from Berdyansk State Pedagogical University. The experimental group used the VirtualBox-based virtual laboratory, while the control group used a traditional hardware network laboratory.

The results showed positive dynamics in the levels of knowledge acquisition and skill development in both groups, but the improvement was more pronounced in the experimental group. The share of students who completed 75-90% of the tasks increased by 14% (vs 5% in the control), and those completing more than 50% of advanced tasks increased by 40% (vs no change in the control). Statistical tests confirmed significant differences in the learning outcomes of the two groups after the experiment.

The research “Integration of laboratory equipment in remote learning environments” by Vasylieva et al. [45] examines the integration and implementation strategies for laboratory work within remote learning environments, alongside an analysis of virtual laboratories as an alternative to traditional practical training. The study is motivated by the unprecedented challenges faced by higher education institutions in conducting laboratory instruction during the COVID-19 pandemic and the ongoing Russian invasion of Ukraine. These crises have catalyzed a rapid transition from physical to virtual learning spaces, necessitating innovative solutions for practical skill development, particularly in technical disciplines.

The paper begins by reviewing the global impact of the pandemic on education, highlighting the mass disruption of learning activities and the digital divide in access to personal computers and internet connectivity. It then discusses the expansion of web-based distance education in higher education and the need for constant improvement in technological and methodological support. Research on the effectiveness, advantages, and barriers of online learning is emphasized, alongside the importance of engaging students in the virtual environment.

The integration of laboratory work in remote settings is identified as a critical challenge, especially for STEM fields that require interaction with physical equipment. Remote and virtual laboratories are proposed as potential solutions, with the former involving real equipment controlled via software and hardware interfaces and the latter emulating experiments through mathematical models.

The case study focuses on the laboratories of bioelectronics and biomechanics at the Department of Computer Information Technologies, Donbas State Engineering Academy. These labs are equipped with modern computer numerical control (CNC) machines and 3D printers, which allow students to translate computer models into physical objects. The CNC machines include the Krechet-4060 for 2D/3D milling and the Sherline 5410 and 4410 for drilling, milling, and turning. The FARM2 3D printer is used for additive manufacturing with various plastics.

While full automation of these machines for remote operation is currently infeasible due to the need for human intervention in specific tasks (e.g., tool/material changeout), the paper explores possibilities for remote monitoring and control. Existing solutions using open-source firmware, single-board computers, and client-server architectures are reviewed. For example, the RepRap system enables web-based control of 3D printers, with potential enhancements through sensor integration and machine learning for quality monitoring.

The universal testing machine UIT STM 001 is also considered for remote laboratory work on the mechanical properties of materials. In addition to partial remote access, virtual laboratory simulations are proposed as an alternative approach. A prototype virtual lab for a “Resistance of Materials” course is described (figure 3), which replicates the entire experimental cycle from sample preparation to data analysis.

The study “Developing pre-service teachers’ digital competence through informatics disciplines in teacher education programs” by Moiseienko et al. [46] investigated the effectiveness of the proposed didactic conditions and structural-functional model for developing pre-service teachers’ digital competence through informatics disciplines in teacher education programs. The rapid digitalization of society and education has highlighted the need for educators to possess a high level of digital competence to integrate digital technologies into their professional practice effectively. However, studies have revealed that pre-service teachers often lack sufficient digital competence, suggesting that existing informatics courses do not adequately contribute to the full and targeted development of this competence.

To address this issue, a structural-functional model was developed, incorporating three specific

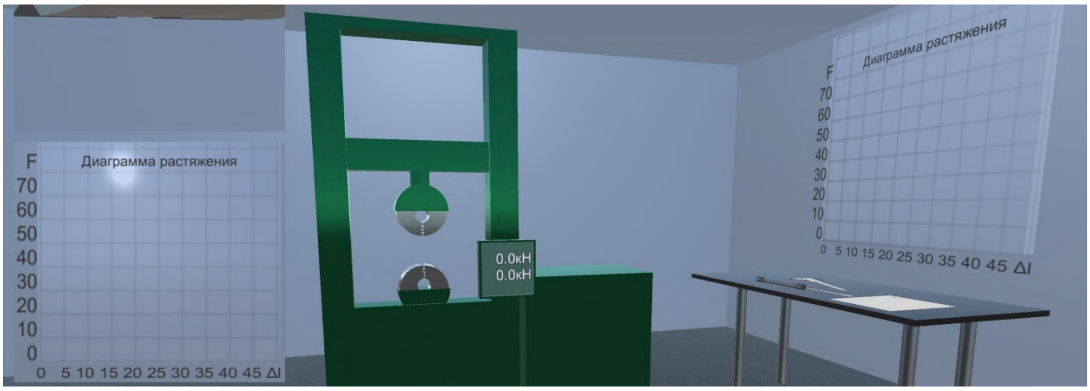

Figure 3: Program interface with three-dimensional models, interface, and mini cameras for simultaneous control of all processes [45].

didactic conditions:

1. Motivational conditionality of subjects' interaction in the digital learning environment.
2. Structuring of educational information in problematic, heuristic and integrative learning models and its translation into project activities.
3. Ensuring a systematic, complicated nature of students' learning activities with diagnostics and timely correction of outcomes using modern ICT.

A pedagogical experiment was conducted to test the effectiveness of the proposed didactic conditions and model. The study followed a quasi-experimental design with a control group ($n = 93$) and an experimental group ($n = 95$) of pre-service teachers from two Ukrainian pedagogical universities over four academic years. The control group studied according to traditional informatics discipline programs, while the experimental group followed an experimental program implementing the proposed didactic conditions and model.

Digital competence formation was assessed according to four structural-criterial components (motivational-value, cognitive-informational, operational-activity, and personal-reflexive) using a range of diagnostic methods, including tests, questionnaires, interviews, practical tasks, competency matrices, expert evaluations, case studies, educational projects, and reflective blogs.

The experimental group demonstrated positive, statistically significant dynamics in the levels of digital competence formation compared to the control group, with the greatest development observed in the cognitive-informational (+35.79%) and motivational-value (+25.26%) components. Paired-sample t-tests revealed significant improvements in the experimental group's digital competence scores across all four components, while independent-sample t-tests showed significantly higher post-experiment scores for the experimental group compared to the control group.

Qualitative findings from thematic analysis of interviews, case studies, educational projects, and blog entries revealed several key themes related to the development of digital competence in the experimental group, including enhanced motivation and engagement, improved understanding of digital technologies, increased confidence in using digital tools, collaborative learning and peer support, and reflective practice and self-awareness.

The results confirm the effectiveness of the proposed didactic conditions and structural-functional model for developing pre-service teachers' digital competence through informatics disciplines. The findings underscore the importance of adopting a holistic, integrated approach to informatics disciplines, combining technical skills, pedagogical knowledge, and practical application through authentic, project-based learning experiences.

The study has implications for teacher education policy and practice. It suggests the need to prioritize the intentional and systematic development of pre-service teachers' digital competence, adopt evidence-based strategies, and invest in necessary infrastructure, resources, and support systems. Future research could explore the long-term impact of digital competence development interventions and adapt the proposed model for different contexts and specializations within teacher education.

The adoption of the new Law of Ukraine “On Education” in 2017 granted greater autonomy to schools in academic, organizational, financial and personnel matters. This shift requires new approaches to train school principals and directors in strategic management skills. The paper “Implementing business simulation games for strategic management training of educational leaders in Ukraine” by Pazdrii and Kuprievych [47] explores the use of business simulation games as an innovative tool to develop the economic and managerial competencies needed by educational leaders to navigate these reforms.

The authors conducted a case study of training held in Ukraine from 2016 to 2021 that utilized business simulations. Over 1,200 participants from preschool, secondary, vocational and higher education institutions were surveyed regarding their perceptions and learning outcomes. The results highlighted a gap between how schools and private businesses perceive key concepts like customers, products and resources. Over 50% of directors agreed schools are economic entities, 87% saw students as the “raw material”, and clients were identified as parents, the state, universities and sometimes businesses. However, some directors rejected applying classical management principles to schools.

The paper identifies several objective reasons for this disconnect, including the legacy of the industrial economy, the absolutism of the socialist system, and low human value in the USSR. Subjective factors were also noted, such as unwillingness to change, lack of tools to transition from public administration to autonomy, legislative uncertainty, and a lack of mutual understanding between the educational and business communities.

To overcome these challenges, the authors propose a systemic approach to economic management training that engages all levels – customers (students), teachers, deputy principals and principals. For leaders, it recommends viewing schools as non-profit economic organizations optimizing limited resources. Deputies are encouraged to expand their roles to encompass marketing, finance and HR. External stakeholder engagement with other schools, clients, businesses and authorities is also emphasized as crucial.

The paper reviews different training technologies and concludes that business games and simulations are the most accessible and impactful for quickly developing practical skills. Gamification and virtual reality, while promising, are seen as too resource-intensive and immersive for time-constrained principals. The authors share best practices and lessons learned from delivering over 120 simulation-based trainings to 600+ educational leaders from 2015-2020. Key success factors included setting expectations to challenge traditional thinking, explaining economic terminology, updating digital skills, providing guidance on interpreting results, and linking the simulation to real-world education sector reforms.

The adoption of digital technologies in education has accelerated rapidly in recent times, driven by technological progress and catalyzed by the global COVID-19 pandemic. The article “The educational technology landscape in Ukraine” by Nehrey and Zomchak [48] analyzes the present landscape and prospects for Educational Technology (EdTech) in Ukraine.

Efficiency analyses using the Data Envelopment Analysis (DEA) methodology were performed to assess the effectiveness of education expenditures in Europe and Central Asia. The results revealed substantial opportunities for Ukraine to enhance educational outcomes via increased investment and technology integration. While European countries generally demonstrated effective education spending, Ukraine and other former Soviet countries exhibited extremely inefficient expenditures. A second DEA model evaluating the efficiency of education in producing an advanced labour force showed that countries with lower spending on education, like Ukraine, achieved higher efficiency than those with significant expenditures, like Germany. These findings suggest great potential for productivity gains through EdTech innovations in Ukraine.

Globally, venture capital funding for EdTech reached a peak during the pandemic but has since declined to pre-2017 levels. China has been the top investor over the past decade, with the US and Europe trailing significantly behind. The Ukrainian EdTech startup ecosystem has expanded to over 80 companies, with 11 projects recognized among the top 200 in Europe by HolonIQ. These startups deliver solutions spanning tutoring (Preply), language instruction (EnglishDom), MOOCs (Prometheus), K-12 education (EdPro), information platforms (Osvitoria), learning management systems (Na Urok, eTutorium), IT education (Mate academy), and writing tools (Grammarly).

A comparative analysis of prominent Ukrainian EdTech projects highlighted their strengths, such as reaching large audiences, leveraging innovative technologies, and offering practical solutions. However, challenges were also identified, including limited mobile applications, high product costs, lack of offline support, and strong competition.

A SWOT analysis of Ukraine's EdTech ecosystem revealed critical internal factors. Strengths included growing government and private sector demand for digital education and the potential for productivity gains. Weaknesses encompassed high technology costs, financing difficulties, bureaucratic hurdles, underdeveloped infrastructure, and lack of impact data. External opportunities were identified in the large student population, data-driven insights for educational improvement, and potential for workforce optimization. Threats included cybersecurity risks, inconsistent outcomes across contexts, and the potential for data access to exacerbate inequalities.

To fully realize the potential of EdTech in Ukraine, the authors recommend several strategic priorities:

1. Increase government spending on education and innovative technologies
2. Ensure access to financing for EdTech startups
3. Accelerate the digitalization of education through affordable ICT and e-government initiatives
4. Engage non-governmental organizations in promoting EdTech adoption
5. Create an enabling environment for the development of the EdTech ecosystem

Educational technology is a dynamic field with continuous developments and innovations shaping research directions and priorities. The Educational Technology Quarterly (ETQ) offers valuable insights into evolving trends within this domain through its broad publication of studies across various educational contexts and technologies. The paper "Shifting sands: analyzing trends in educational technology research published in Educational Technology Quarterly (2021-2023)" by Semerikov et al. [49] provides a bibliometric analysis of 72 research articles published in ETQ from 2021-2023 to identify key themes and changes in focus over this period.

The study utilized the VOSViewer software tool to conduct a bibliometric analysis of the abstract corpus. Author keywords were extracted, and maps of co-occurring keywords were generated and visualized (figure 4). Various bibliometric techniques were applied, including keyword analysis, temporal analysis, network analysis of co-occurrences, and geographic analysis of author locations.

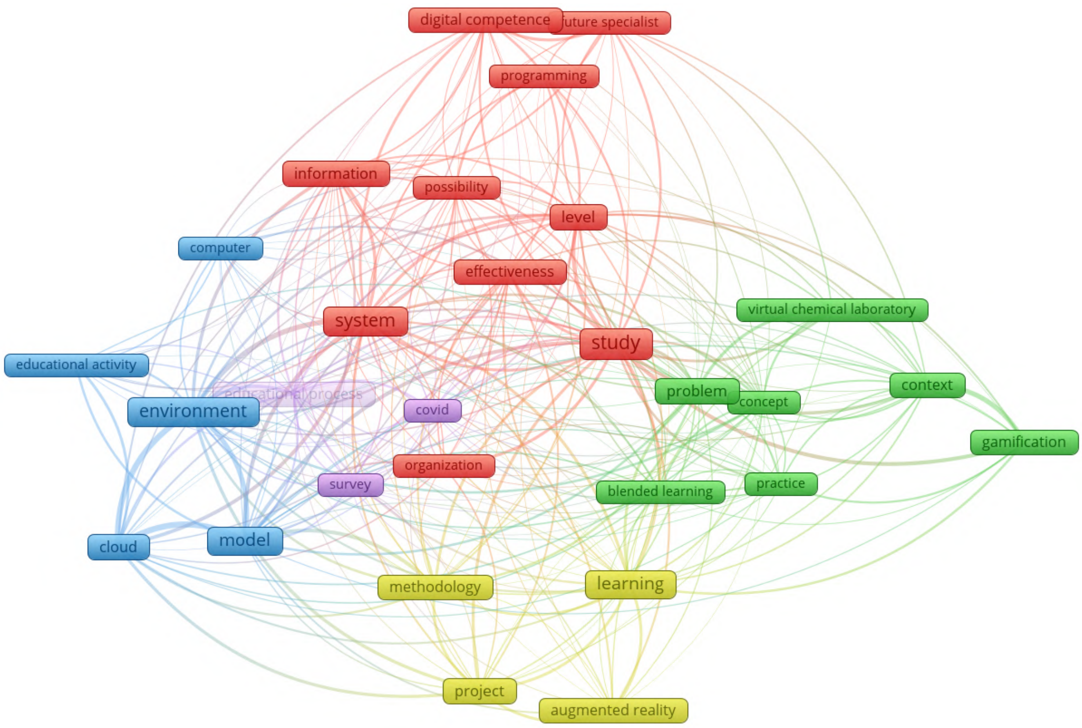

Figure 4: Co-occurrence network of keywords [49].

The keyword analysis revealed five distinct clusters of research topics:

1. Digital competence development and technology systems
2. Pedagogical models and educational concepts
3. Technological infrastructure and frameworks
4. Research methods and processes
5. COVID-19 pandemic-related research

Central keywords spanning multiple clusters, such as "learning", "level", "problem", and "effectiveness", indicated interdisciplinary topics connecting these research domains.

The temporal analysis mapped keywords by their publication dates, revealing patterns and changes in research focus over time. COVID-19-related terms emerged abruptly in 2021 and remained frequent, reflecting a surge in pandemic-driven research. "Cloud" gained traction in 2021, pointing to growing attention on cloud-based technologies and remote learning. Newer topics like "gamification" and "virtual chemical laboratory" gained prominence in 2022 and 2023. By 2023, keywords like "methodology", "problem", and "programming" overtook some earlier topics, indicating a return to more foundational research as the acute pandemic period receded. "Digital competence" displayed a rapidly growing, sustained interest since 2022.

The network analysis revealed strong linkages between keywords, such as "learning" and "level", and "cloud" and "environment." "Model" and "problem" formed connections across multiple clusters, suggesting their interdisciplinary nature. Peripheral keywords like "future specialist" and "virtual chemical laboratory" had fewer connections, pointing to their more domain-specific focus.

The geographic analysis of author affiliations highlighted the global distribution of research published in ETQ. While Ukraine dominated with 69% of publications, contributions from other countries, particularly Poland, the United States, and Israel, were notable. The proportion of contributions from Middle Eastern and African countries grew from 0% in 2021 to 25% in 2023, indicating increasing global diversification.

This bibliometric analysis provides quantitative evidence of recent trends and the evolving landscape of educational technology research in ETQ. The findings portray a field adapting to current shocks like the COVID-19 pandemic while expanding in scope and attention to longer-term priorities like enhancing digital skills. However, this study represents only a preliminary examination, and further work could conduct more sophisticated statistical analyses, contextualize the findings within broader technological and educational contexts, and compare ETQ's coverage with other journals in the field.

3.2. Augmented reality gamification

Gamification, the use of game design elements in non-game contexts, is a promising approach for enhancing motivation and engagement in software engineering education. However, its applications and effects are not yet well understood. The paper "A systematic review of gamification in software engineering education" by Korniienko et al. [50] aimed to synthesize the current state of evidence on the use and impacts of gamification in software engineering education.

The review followed the PRISMA 2020 guidelines (figure 5). Scopus searched for peer-reviewed papers published up to March 1, 2023, that described empirical studies of gamification in software engineering courses and measured impacts on learning outcomes and/or student perceptions. Study characteristics, gamification approaches, software engineering topics, research methods, and key findings were extracted. The risk of bias was assessed using an adapted ROBINS-I tool. Quantitative and qualitative results were synthesized narratively, and the certainty of evidence was evaluated using the GRADE approach.

Twenty-nine studies met the inclusion criteria. The studies most commonly employed points (17 studies), challenges (14 studies), leaderboards (11 studies), and badges (9 studies) to gamify the learning of software process (12 studies), software design (9 studies), and software professional practices (7 studies). The majority of studies (21) reported positive impacts on student engagement, motivation, and/or performance, but the lack of validated measurement instruments and controlled study designs

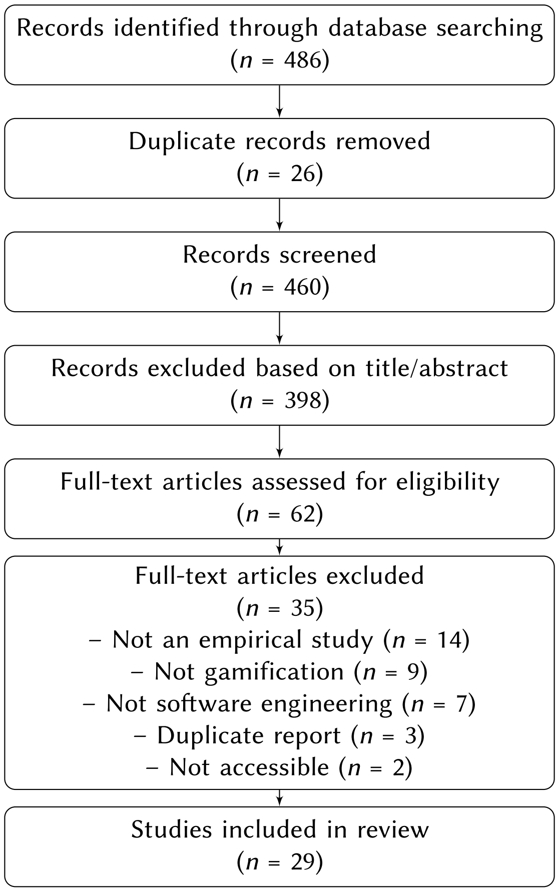

Figure 5: PRISMA flow diagram of the study selection process [50].

limited the quality of evidence. Most studies (18/29) had a serious overall risk of bias, primarily due to confounding and selection bias. The certainty of evidence was rated as low or very low for all outcomes.

The review found that a variety of gamification strategies have been applied in software engineering education, primarily in university courses. The impacts on learning outcomes were generally positive but small and inconsistent across studies. The effects on student engagement and motivation were more consistently positive, but the evidence was of very low certainty. User experiences and acceptance of gamified learning activities were mostly positive but with low certainty evidence. The heterogeneity in gamification designs, software engineering topics, and educational contexts, as well as the methodological limitations of the primary studies, precluded robust quantitative synthesis and definitive conclusions about the effectiveness of gamification.

Gamification appears to be a promising approach for enhancing software engineering education, but more rigorous, theory-driven research is needed to identify effective strategies for specific learning objectives and contexts. Educators and researchers should carefully consider how specific gamification elements align with target competencies and pedagogical principles, balance extrinsic rewards and intrinsic motivation, engage students as co-designers, and plan for the resources and support needed for successful implementation.

This systematic review found that gamification is an increasingly popular but under-researched approach in software engineering education. While the evidence suggests some positive impacts, particularly on student engagement and motivation, the certainty of the evidence is low. Future research should employ rigorous, controlled designs and validated measures to evaluate the effectiveness of specific gamification strategies for targeted software engineering learning outcomes. Attention to implementation fidelity and the resources needed to overcome potential barriers will also be critical for realizing the potential of gamification to transform software engineering education.

The study "Gamification in higher education: methodology" by Yechkalo et al. [51] examines the implementation of gamification in higher education, focusing on its effectiveness and pedagogical conditions. Gamification, the application of game-design elements and principles in non-game contexts, has emerged as a promising approach to enhance student engagement and learning outcomes. However, its successful integration into higher education requires careful consideration of pedagogical conditions and a systematic methodology.

The research presents a structural-functional model for gamification in higher education, comprising five key blocks: objective, content, methodological-organizational, diagnostic, and resultant (figure 6). The objective block defines the purpose and objectives of the educational process, while the content block includes the pedagogical conditions for effective gamification use. The methodological-organizational block outlines the technology for implementing gamification, and the diagnostic block specifies criteria and levels for evaluating its effectiveness. Finally, the resultant block establishes the desired outcome of the model's implementation.

Two key pedagogical conditions are proposed to increase the effectiveness of gamification in higher education significantly:

1. Developing positive motivation for using gamification by engaging students in quasi-professional activities that simulate real-world problem situations.
2. Strengthening the practical orientation of the educational process based on the principles of variability and combining traditional and innovative methods, forms, and activities.

These conditions aim to enhance student motivation, bridge the gap between theory and practice, and promote the development of relevant professional skills.

To validate the proposed methodology and pedagogical conditions, a pedagogical experiment was conducted involving control and experimental groups of students. The effectiveness of gamification was evaluated using three criteria: motivational, cognitive, and operational, each with four levels: high, sufficient, medium, and low. These criteria were assessed using various indicators, such as students' interest and participation in learning activities, completeness and systematicity of knowledge, and ability to apply skills in professional contexts.

The results of the formative stage of the experiment showed significant improvements in the experimental group across all three criteria. The proportion of students demonstrating high levels of gamification effectiveness increased, while those at medium and low levels decreased. These changes were more pronounced in the experimental group compared to the control group, highlighting the impact of the implemented methodology and pedagogical conditions.

3.3. Design and implementation of augmented reality learning environments

The paper "Designing an immersive cloud-based educational environment for universities: a comprehensive approach" by Semerikov et al. [52] presents a comprehensive approach to designing an immersive cloud-based educational environment (ICBEE) for universities. As digital transformation advances in higher education, there is a growing need for innovative learning environments that leverage cutting-edge technologies to enhance the quality and accessibility of educational services. Immersive learning approaches based on augmented reality (AR) and virtual reality (VR), combined with the power and flexibility of cloud computing, offer new opportunities for creating interactive, engaging, and practice-oriented educational experiences.

The paper defines an ICBEE as an integrated system that combines AR/VR tools, cloud services, learning management platforms, and various educational resources and activities to support learning, research, and management processes in a university setting. The design and implementation of such environments require a solid scientific and methodological foundation that considers the complex interplay of technological, pedagogical, and organizational factors.

The paper identifies the main structural components of ICBEE as spatial-semantic, technological, content, communication, and immersive. These components form an integrated system in which physical and digital spaces are blended, cloud-based tools and platforms mediate the learning process, and immersive technologies add an extra layer of interactivity and engagement.

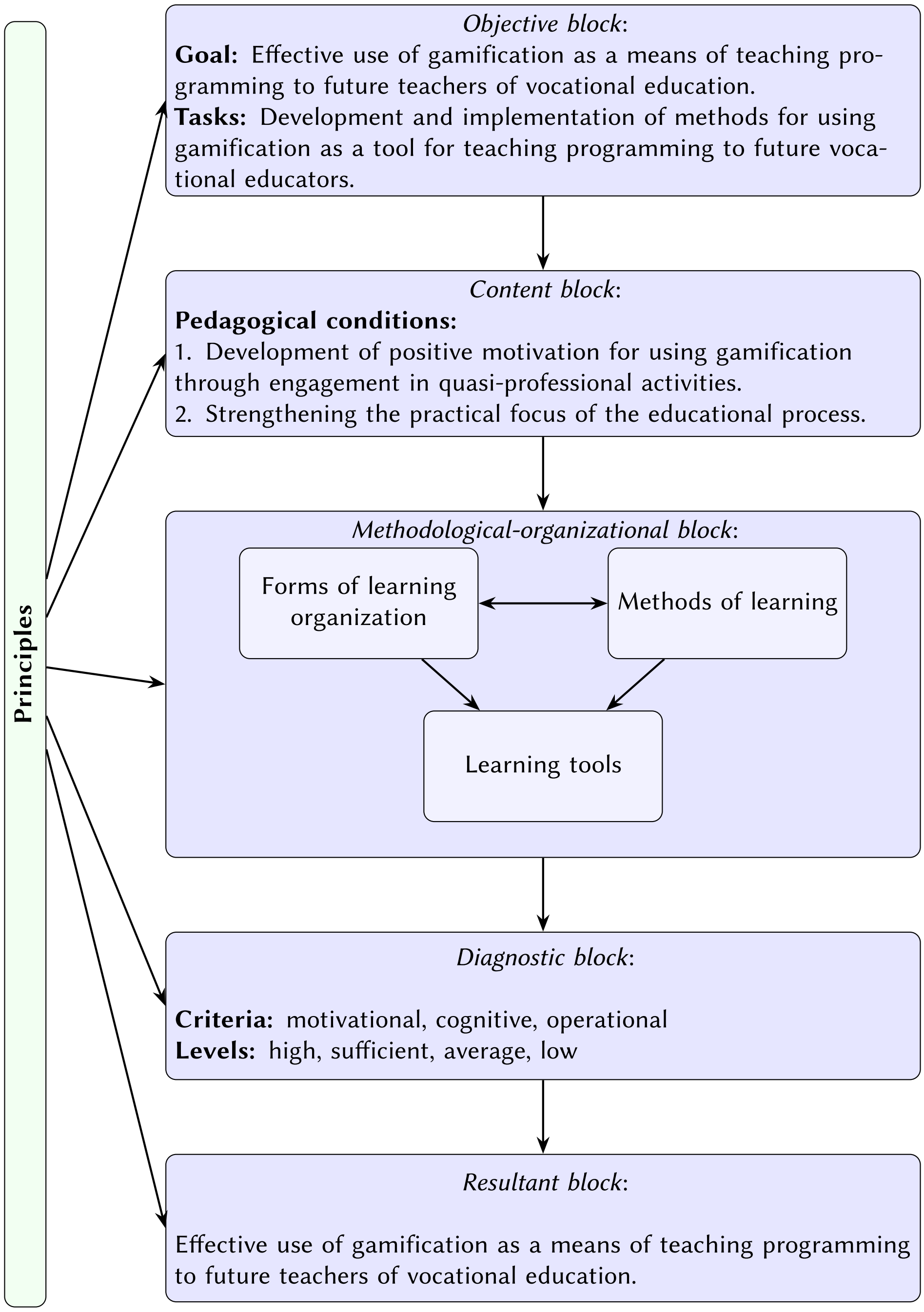

Figure 6: Structural-functional model for gamification in higher education [51].

The functional modules and services of ICBEE include a learning management module, immersive learning content authoring and delivery module, institutional repository module, learning analytics and reporting module, communication and collaboration services, and IT infrastructure management and security services. The integration and interoperability of these modules and services are essential for creating a seamless and effective educational experience.

The paper also discusses the principles of designing immersive learning experiences, such as interactivity and engagement, realism and authenticity, adaptability and personalization, multimodality and multisensory feedback, collaborative and social learning, and safety and ethics. Guidelines for developing educational AR applications and approaches to designing VR simulations and training systems are provided, along with specific examples.

The proposed general metamodel of ICBEE captures its essential elements and their relationships, consisting of four main layers: infrastructure, platforms and services, educational content and applications, and learning and research activities (figure 7). The metamodel highlights the cross-cutting aspects of ICBEE, such as the development of learners' digital competencies and the integration and interoperability of different components and services.

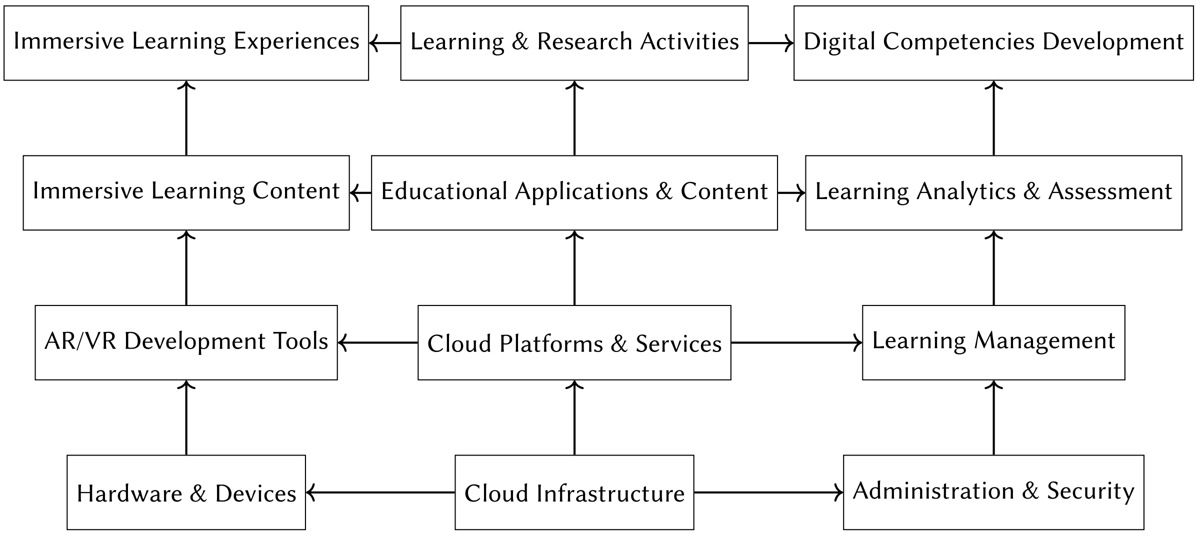

Figure 7: General metamodel of ICBEE [52].

3.4. Augmented reality in science education

The article "Enhancing mathematics education with GeoGebra and augmented reality" by Kramarenko et al. [53] explores the potential of integrating GeoGebra software with augmented reality technology to enhance mathematics education. GeoGebra, a powerful dynamic mathematics software, allows for the interactive exploration of mathematical concepts through dynamic visualizations. Its recent venture into AR, with GeoGebra AR applications, presents exciting opportunities for engaging students with mathematical ideas in innovative ways.

The article examines current research on GeoGebra AR in mathematics education and provides examples of its applications across various mathematical domains and educational levels. In secondary mathematics education, studies have shown that integrating GeoGebra AR improves students' spatial intelligence, academic performance, and problem-solving skills compared to traditional instruction. GeoGebra AR has been applied to topics such as geometry (visualizing 3D shapes, exploring cross-sections), algebra (graphing functions), and trigonometry (exploring graphs and transformations).

In higher education and STEAM (Science, Technology, Engineering, Arts, and Mathematics) contexts, GeoGebra AR has been used to enhance learning in calculus (visualizing 3D graphs and solids of revolution), engineering mathematics (spatial geometry), and interdisciplinary projects that connect mathematics with arts, culture, and history. These applications demonstrate the versatility of GeoGebra AR in promoting visualization, conceptual understanding, and authentic learning experiences.

The article also discusses the potential of AR technology to support and enhance key aspects of mathematical thinking. GeoGebra AR can serve as a tool to connect abstract mathematical knowledge to real-world situations, enable hypothesis testing and knowledge construction through the manipulation of AR models, and afford novel embodied interactions related to perspective, scale, and depth. However, more research is needed to unpack the cognitive processes involved and design AR-based tasks that optimize learning.

A case study on stereometry teaching is presented, showcasing tasks on combinations of polyhedra and solids of revolution, stereometric problems of applied content, and project work in GeoGebra 3D (figure 8). The case study highlights how AR can provide dynamic visualizations of 3D geometrical shapes, foster understanding of their relationships and construction methods, and enable intuitive hand gesture-based interactions. Project work, such as modelling playgrounds or artists' rooms, can integrate GeoGebra AR to develop students' STEM competencies, critical thinking, creativity, and collaboration skills.

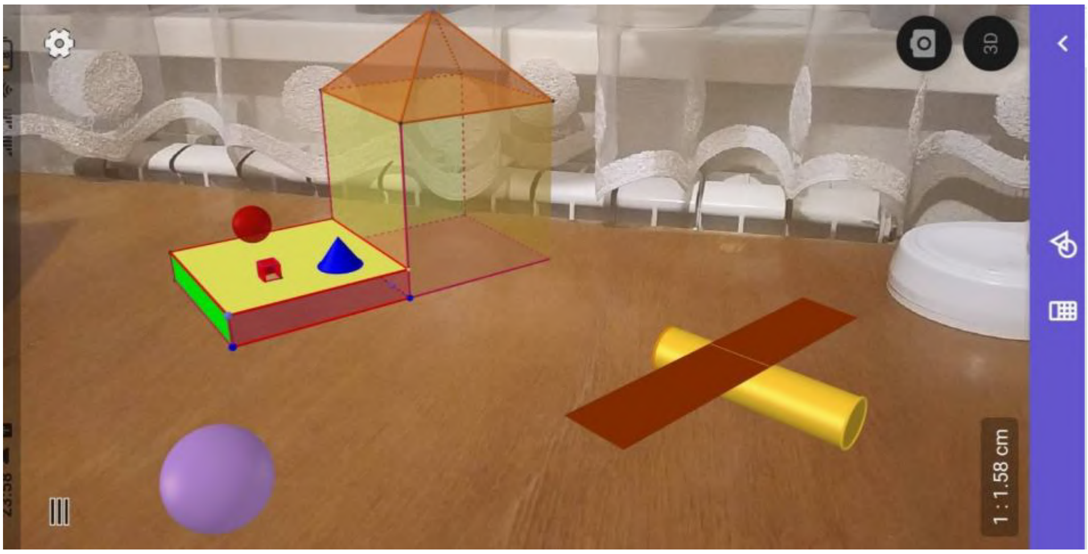

Figure 8: Sample implementation of the project "Playground" [53].

To effectively incorporate GeoGebra AR into mathematics curricula, the article recommends aligning AR activities with learning objectives, providing clear instructions and scaffolding, encouraging collaborative learning, assessing learning outcomes, and gathering feedback for iterative refinement. Professional development for teachers is crucial, as is attention to technological infrastructure and equity.

The increasing digitalization of education has highlighted the need for pre-service teachers in mathematics, physics and computer science to develop competencies in effectively utilizing information and communication technologies (ICT) in their teaching practice. Free and open-source software (FOSS) presents a valuable opportunity for educators to access powerful tools without the financial and legal barriers associated with proprietary software. The article "The utility of free software in the teaching of mathematics, physics and computer science for pre-service teachers" by Velychko and Fedorenko [54] examines the theoretical and methodological foundations for integrating FOSS into the professional training of pre-service teachers in these disciplines.

The study proposes a system for applying FOSS in teacher education, encompassing conceptual, content and technological components (figure 9). The conceptual subsystem outlines the goals, approaches, and principles of the system, with the primary objective of enhancing pre-service teachers' ICT competencies through FOSS. The content subsystem defines the structure of these competencies, emphasizing areas such as information and data literacy, digital content creation, and problem-solving. It also highlights the importance of open educational resources and e-learning. The technological subsystem focuses on the practical implementation, including stages of competency development, teaching methods, FOSS tools, and learning formats.

The effectiveness of the proposed system was evaluated through an experimental study involving 240 students from pedagogical universities in Ukraine. The results showed that the experimental group taught using the FOSS-based system, demonstrated significantly higher levels of ICT competency compared to the control group. In particular, they exhibited better skills in using FOSS tools for problem-solving, digital content creation and collaboration. The study also found a positive impact on student's motivation and confidence in their ability to integrate technology into their future teaching practice.

The paper discusses the benefits of FOSS in education, including cost savings, flexibility, skill development, and opportunities for collaboration. However, challenges such as lack of awareness, technical support, and training for educators have also been acknowledged. To address these, the authors propose

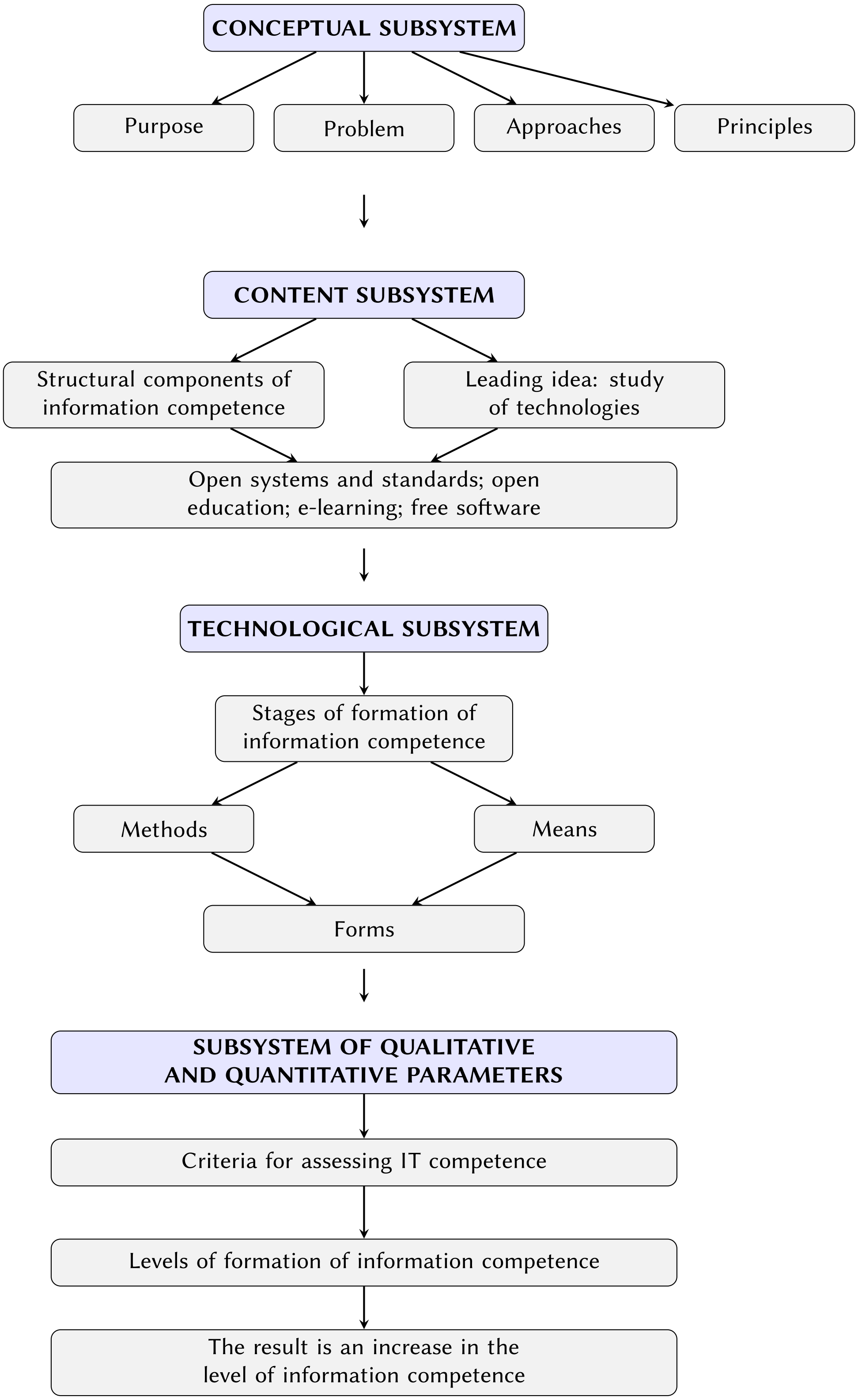

Figure 9: System for integrating free software into the professional training of pre-service teachers of mathematics, physics and computer science [54].

recommendations for integrating FOSS into teacher education programs:

1. Raise awareness about the benefits of FOSS among stakeholders
2. Provide training and support for educators to use FOSS tools effectively
3. Encourage collaboration and resource sharing within and across institutions

4. Integrate FOSS into the curriculum across disciplines
5. Foster partnerships with FOSS communities and industry

3.5. Augmented reality in professional training and retraining

Understanding the dynamics and outcomes of combat engagements is critical for analyzing military tactics, identifying best practices, and developing practical recommendations. However, open-source information on past battles is often incomplete, biased, or lacking the necessary detail for thorough analysis. Seeking to address this challenge, the paper "Interactive 3D visualizations for studying combat experiences and life cycles" by Barkatov et al. [55] proposes the use of interactive 3D visualizations in conjunction with the After Action Review (AAR) methodology and mathematical combat modelling to reconstruct and analyze combat experiences.

The key criterion for assessing the 3D visualizations is the degree of their adequacy to the actual combat episode in terms of stages, timeline, and elements. The visual information should approach reality maximally. Proposed criteria include information completeness and reliability, battle dynamics, effectiveness of combat actions, and accurate representation of terrain characteristics. NATO's AAR methodology, which focuses on establishing the facts, analyzing the causes and contributing factors, and deriving actionable lessons, is employed to structure the analysis.

Mathematical modelling of combat using Lanchester's equations complements the AAR by quantifying the dynamics and outcomes of engagements. By considering different initial force ratios, attrition rates, and engagement termination conditions, analysts can explore the sensitivity of outcomes to various factors and highlight the leverage points for achieving desired results.

The design of an effective combat visualization system follows principles of modularity, scalability, interoperability, user-centricity, and extensibility. The pipeline involves the formation, geometric processing, and rasterization of reliable data, while control programs handle initialization and interaction with the external environment (figure 10). Techniques such as discarding invisible terrain sections and reducing the utilization of distant areas help to optimize performance.

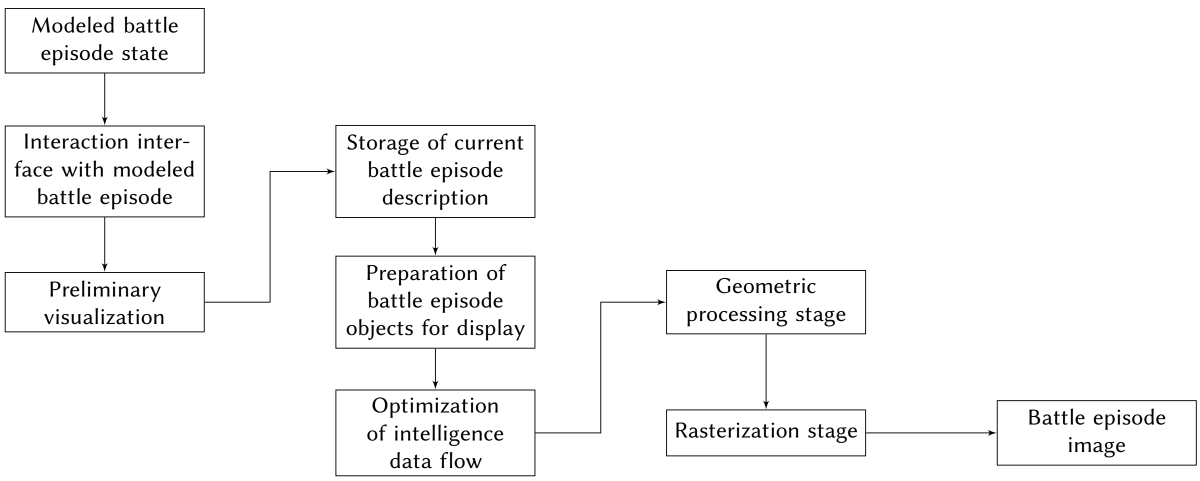

Figure 10: Battle episode visualization system [55].

The process of creating interactive 3D visualizations of combat episodes involves a systematic approach to data collection, terrain and entity modelling, animation, and interactive rendering. Key steps include:

1. Gathering and analyzing information from various sources to reconstruct the battle in sufficient detail.
2. Building a 3D model of the terrain using a digital elevation model and overlaying relevant features.
3. Placing 3D models of personnel, vehicles, and equipment according to their initial positions.
4. Animating the actions of each entity throughout the battle based on the collected data.

5. Integrating additional elements to enhance the immersion and information content of the visualization.
6. Rendering the complete visualization and packaging it for interactive display on various platforms.

The methodology is demonstrated through two case studies from the war in Eastern Ukraine: the defence of the "Seroga" strongpoint near Sanzharivka on January 28, 2015, and the assault on Logvinove on February 12, 2015. For each case, the 3D visualization was created using the Interactive 3D Visualization Constructor software, which allowed users to freely move the camera, pause and resume the playback, and toggle information overlays.

The AAR of these battles identified several key lessons, including the importance of well-prepared defensive positions, the decisive role of artillery and MLRS, the value of timely and organized withdrawals, and the criticality of situational awareness and rapid decision-making. These lessons were subsequently incorporated into training and doctrine for Ukrainian mechanized units.

Beyond AAR, the visualizations served as case studies for professional military education, exposing students to the complexity and chaos of modern combat. The realistic and immersive nature of the presentations also facilitated understanding and communication of the battles' significance when briefing senior leaders.

As the fidelity and sophistication of modelling and simulation technologies advance, the potential applications of interactive 3D visualization in the military domain will only expand. From mission planning and rehearsal to after-action review and training, immersive visualizations will play an increasingly central role in preparing the armed forces for the challenges of 21st-century warfare.

The rapid advancement of digital technologies is transforming educational practices across all sectors, with immersive technologies like virtual reality at the forefront of this revolution. In vocational higher education, there is growing interest in using VR to enhance students' professional training. VR offers unique affordances for creating realistic simulations of workplace environments, allowing students to practice skills in safe, controlled settings and providing experiences that would be difficult or impossible to replicate in traditional educational contexts.

The paper "Methodical foundations and implementation strategies for virtual reality in professional training of vocational higher education students" by Yechkalo and Tkachuk [56] aim to provide comprehensive methodical foundations for implementing VR in the professional training of vocational higher education students. The researchers present a detailed model for VR integration, outline key pedagogical conditions, and offer evidence-based recommendations for educators and institutions.

The proposed model consists of five interconnected components: the goal block, theoretical-methodological block, content block, organizational-methodological block, and diagnostic-resultant block (figure 11). The goal block focuses on defining clear, measurable learning objectives that align VR activities with overall curriculum goals and industry skill requirements. The theoretical-methodological block draws on established learning theories while leveraging the unique affordances of VR, incorporating principles like experiential learning, situated learning, and collaborative learning. The content block outlines strategies for designing VR learning content and activities, including realistic modelling, interactive elements, scenario-based learning, and feedback mechanisms. The organizational-methodological block addresses the practical considerations of VR implementation, such as technology infrastructure, instructor training, student orientation, and health & safety protocols. The diagnostic-resultant block emphasizes the importance of ongoing assessment and evaluation to refine and improve VR integration.

The paper also identifies two key pedagogical conditions for effective VR use: motivation for professional activities and integration of VR methodology. Enhancing student motivation through realistic previews of workplaces, low-stakes experimentation, and gamified skill development is crucial. Integrating VR into the curriculum coherently and systematically, rather than treating it as an isolated tool, is essential for maximizing its educational impact.

A particularly promising application of VR in vocational training is the creation of virtual workshops and laboratories. These immersive environments allow students to practice using specialized equipment, conduct experiments, troubleshoot scenarios, collaborate on projects, and explore dangerous or hard-to-access settings—all without the risks and costs associated with physical facilities. Key features of

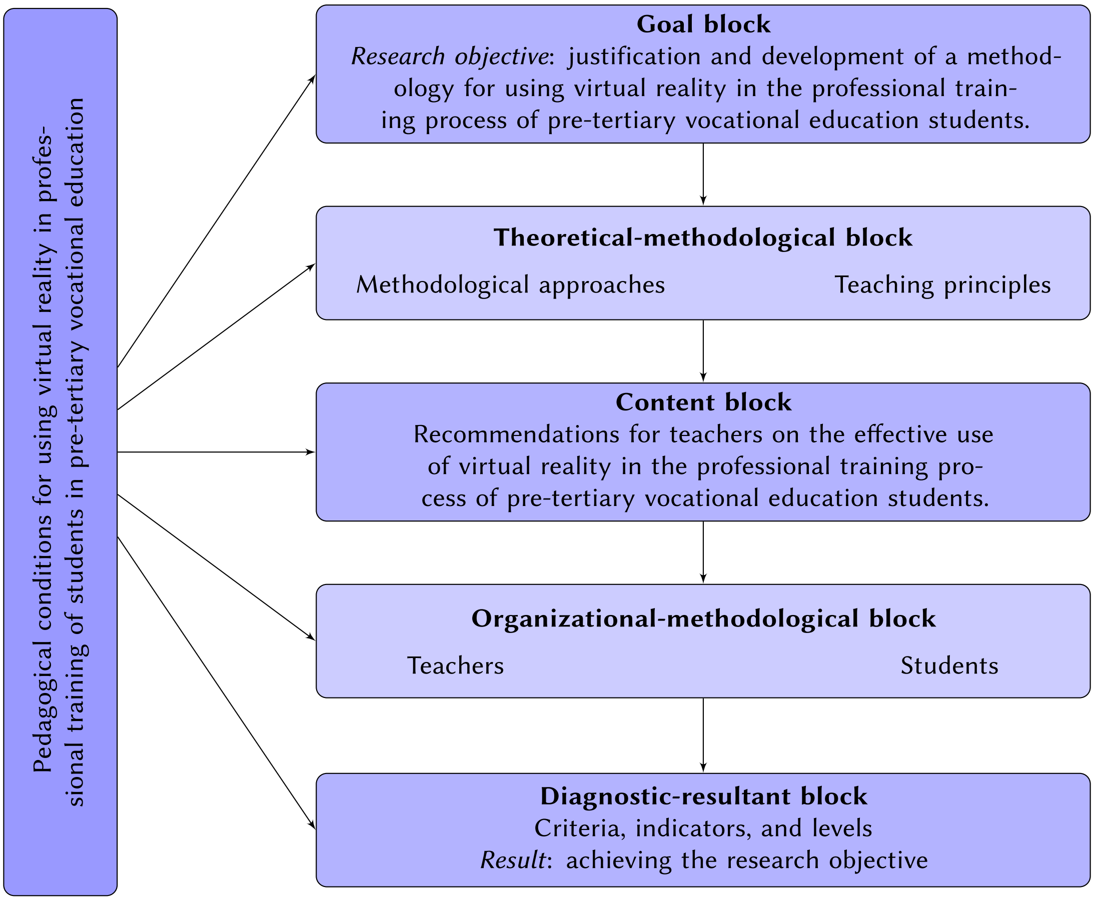

Figure 11: Comprehensive model for integrating VR in vocational higher education [56].

effective virtual workshops include high-fidelity 3D modelling, physics-based interactions, customizable scenarios, data analytics, and multi-user functionality.

The paper provides detailed implementation recommendations, emphasizing the importance of starting with small-scale pilot projects, providing comprehensive instructor training, aligning VR activities with existing curricula, and establishing robust assessment mechanisms. Institutions must also address challenges related to high initial costs, student comfort and well-being, skills transfer assessment, technological obsolescence, equity and access, content development, and ethical considerations.

4. Conclusion

The proceedings of the 6th International Workshop on Augmented Reality in Education (AREdu 2023) offer a comprehensive snapshot of the current state of research and practice in this dynamic field. The papers presented at the workshop demonstrate the creativity, rigour, and passion of a global community of scholars and practitioners committed to harnessing the power of AR to enhance teaching and learning.

From theoretical frameworks and methodological innovations to real-world applications and empirical studies, the contributions span a wide range of topics and contexts, reflecting the diversity and vitality of the field. They showcase the potential of AR to revolutionize education by creating immersive, interactive, and personalized learning experiences that foster engagement, motivation, and deep understanding.

At the same time, the proceedings also highlight the challenges and opportunities that lie ahead. Realizing AR's full promise in education will require sustained investment in research and development, teacher preparation and support, infrastructure and resources, and policies and standards that promote equity and excellence. It will also demand ongoing collaboration and dialogue among diverse stakeholders to ensure that the technology serves the needs and aspirations of all learners.

The Academy of Cognitive and Natural Sciences (https://acnsci.org/), in partnership with Kryvyi Rih State Pedagogical University and Kryvyi Rih National University, had the pleasure of hosting the 6th International Workshop on Augmented Reality in Education (AREdu 2023).

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

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

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

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, CEUR Workshop Proceedings (2024) 1–22.

[7] A. E. Kiv, S. O. Semerikov, V. N. Soloviev, A. M. Striuk, First student workshop on computer science & software engineering, CEUR Workshop Proceedings 2292 (2018) 1–10.

[8] R. O. Tarasenko, S. M. Amelina, S. O. Semerikov, V. D. Shynkaruk, Using interactive semantic

networks as an augmented reality element in autonomous learning, Journal of Physics: Conference Series 1946 (2021) 012023. doi:10.1088/1742-6596/1946/1/012023.

[9] I. Georgescu, J. Kinnunen, The role of foreign direct investments, urbanization, productivity, and energy consumption in Finland's carbon emissions: an ARDL approach, Environmental Science and Pollution Research 30 (2023) 87685–87694. doi:10.1007/s11356-023-28680-w.

[10] B. P., G. D., G. F., Using augmented reality devices for remote support in manufacturing: A case study and analysis, Advances in Production Engineering & Management 16 (2021) 418–430. doi:10.14743/apem2021.4.410.

[11] C. Pribeanu, A. Balog, D. D. Iordache, Formative User-Centered Usability Evaluation of an Augmented Reality Educational System, in: J. Cordeiro, B. Shishkov, A. Ranchordas, M. Helfert (Eds.), ICSOFT 2008 - Proceedings of the Third International Conference on Software and Data Technologies, Volume ISDM/ABF, Porto, Portugal, July 5-8, 2008, INSTICC Press, 2008, pp. 65–72.

[12] D. Rodriguez-Andres, M. Mendez-Lopez, M.-C. Juan, E. Perez-Hernandez, A Virtual Object-Location Task for Children: Gender and Videogame Experience Influence Navigation; Age Impacts Memory and Completion Time, Frontiers in Psychology 9 (2018). doi:10.3389/fpsyg.2018.00451.

[13] R. Zender, P. Sander, M. Weise, M. Mulders, U. Lucke, M. Kerres, HandLeVR: Action-Oriented Learning in a VR Painting Simulator, in: E. Popescu, T. Hao, T.-C. Hsu, H. Xie, M. Temperini, W. Chen (Eds.), Emerging Technologies for Education, volume 11984 of *Lecture Notes in Computer Science*, Springer International Publishing, Cham, 2020, pp. 46–51. doi:10.1007/978-3-030-38778-5_6.

[14] G. Kiss, A. Szasz, Analysing of the information security awareness of the economic information technology students, in: 2016 IEEE 17th International Symposium on Computational Intelligence and Informatics (CINTI), 2016, pp. 000213–000218. doi:10.1109/CINTI.2016.7846406.

[15] S. K. Battula, S. Garg, R. Naha, M. B. Amin, B. Kang, E. Aghasian, A blockchain-based framework for automatic SLA management in fog computing environments, The Journal of Supercomputing 78 (2022) 16647–16677. doi:10.1007/s11227-022-04545-w.

[16] A. Kaminskyi, M. Nehrey, N. Rizun, The impact of covid-induced shock on the risk-return correspondence of agricultural etfs, in: A. Kiv (Ed.), Proceedings of the Selected Papers of the Special Edition of International Conference on Monitoring, Modeling & Management of Emergent Economy (M3E2-MLPEED 2020), Odessa, Ukraine, July 13-18, 2020, volume 2713 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2020, pp. 204–218. URL: https://ceur-ws.org/Vol-2713/paper17.pdf.

[17] T. A. Vakaliuk, S. I. Pochtoviuk, Analysis of tools for the development of augmented reality technologies, 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. 119–130. URL: https://ceur-ws.org/Vol-2898/paper06.pdf.

[18] N. Veretennikova, N. Kunanets, Recommendation Systems as an Information and Technology Tool for Virtual Research Teams, in: N. Shakhovska, V. Stepashko (Eds.), Advances in Intelligent Systems and Computing II, volume 689 of *Advances in Intelligent Systems and Computing*, Springer International Publishing, Cham, 2018, pp. 577–587. doi:10.1007/978-3-319-70581-1_40.

[19] R. O. Tarasenko, S. M. Amelina, Y. M. Kazhan, O. V. Bondarenko, The use of AR elements in the study of foreign languages at the university, 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. 129–142. URL: https://ceur-ws.org/Vol-2731/paper06.pdf.

[20] O. Kodym, T. Martoch, L. Kubac, R. Danel, Z. Neustupa, Usage of virtual reality for presentation of full lifecycle of opencast mines with support of internet of things, in: 12th International Multidisciplinary Scientific GeoConference and EXPO - Modern Management of Mine Producing, Geology and Environmental Protection, SGEM 2012, volume 3, 2012, pp. 297–304.

[21] S. O. Semerikov, T. A. Vakaliuk, I. S. Mintii, V. A. Hamaniuk, V. N. Soloviev, O. V. Bondarenko, P. P. Nechypurenko, S. V. Shokaliuk, N. V. Moiseienko, V. R. Ruban, Mask and Emotion: Computer

Vision in the Age of COVID-19, in: Digital Humanities Workshop, DHW 2021, Association for Computing Machinery, New York, NY, USA, 2022, p. 103–124. doi:10.1145/3526242.3526263.
[22] H. Javaheri, A. Gruenerbl, E. Monger, M. Gobbi, P. Lukowicz, Stayin' Alive: An Interactive Augmented: Reality CPR Tutorial, in: Proceedings of the 2018 ACM International Joint Conference and 2018 International Symposium on Pervasive and Ubiquitous Computing and Wearable Computers, UbiComp '18, Association for Computing Machinery, New York, NY, USA, 2018, p. 365–368. doi:10.1145/3267305.3267569.
[23] G. Rotidi, K. Kedraka, E.-M. Frementiti, C. Kaltsidis, University Pedagogy in Greece: Pedagogical Needs of Greek Academics from Ionian University, in: A. Kavoura, E. Kefallonitis, P. Theodoridis (Eds.), Strategic Innovative Marketing and Tourism, Springer Proceedings in Business and Economics, Springer International Publishing, Cham, 2020, pp. 737–744. doi:10.1007/978-3-030-36126-6_81.
[24] O. H. Kolgatin, L. S. Kolgatina, N. S. Ponomareva, Computational modelling of stochastic processes for learning research, in: A. E. Kiv, S. O. Semerikov, V. N. Soloviev, A. M. Striuk (Eds.), Proceedings of the 9th Illia O. Teplytskyi Workshop on Computer Simulation in Education (CoSinE 2021) co-located with 17th International Conference on ICT in Education, Research, and Industrial Applications: Integration, Harmonization, and Knowledge Transfer (ICTERI 2021), Kherson, Ukraine, October 1, 2021, volume 3083 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2021, pp. 1–15. URL: https://ceur-ws.org/Vol-3083/paper296.pdf.
[25] G. Chuiko, O. Dvornik, Y. Darnapuk, Y. Krainyk, Oxygen Saturation Variability: Healthy Adults, in: 2019 XIth International Scientific and Practical Conference on Electronics and Information Technologies (ELIT), 2019, pp. 72–75. doi:10.1109/ELIT.2019.8892319.
[26] 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.
[27] A. E. Kroshilin, V. N. Kukharenko, B. I. Nigmatulin, Particle deposition on a channel wall in a turbulent disperse flow with gradient, Fluid Dynamics 20 (1985) 542–547. doi:10.1007/BF01049887.
[28] 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.
[29] S. O. Semerikov, M. M. Mintii, I. S. Mintii, Review of the course "Development of Virtual and Augmented Reality Software" for STEM teachers: implementation results and improvement potentials, 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. 159–177. URL: https://ceur-ws.org/Vol-2898/paper09.pdf.
[30] S. O. Semerikov, A. M. Striuk, T. A. Vakaliuk, A. Morozov, Quantum information technology on the Edge, in: S. O. Semerikov (Ed.), Joint Proceedings of the Workshops on Quantum Information Technologies and Edge Computing (QuaInT+doors 2021), Zhytomyr, Ukraine, April 11, 2021, volume 2850 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2021, pp. 1–15. URL: http://ceur-ws.org/Vol-2850/paper0.pdf.
[31] 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.

[32] M. V. Marienko, Y. H. Nosenko, M. P. Shyshkina, Smart systems of open science in teachers' education, Journal of Physics: Conference Series 2288 (2022) 012035. doi:10.1088/1742-6596/2288/1/012035.

[33] V. P. Oleksiuk, J. A. Overko, O. M. Spirin, T. A. Vakaliuk, A secondary school's experience of a cloud-based learning environment deployment, in: T. A. Vakaliuk, V. V. Osadchyi, O. P. Pinchuk (Eds.), Proceedings of the 2nd Workshop on Digital Transformation of Education (DigiTransfEd 2023) co-located with 18th International Conference on ICT in Education, Research and Industrial Applications (ICTERI 2023), Ivano-Frankivsk, Ukraine, September 18-22, 2023, volume 3553 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2023, pp. 93–109. URL: https://ceur-ws.org/Vol-3553/paper7.pdf.

[34] K. Osadcha, V. Osadchyi, S. Semerikov, H. Chemerys, A. V. Chorna, The Review of the Adaptive Learning Systems for the Formation of Individual Educational Trajectory, 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. 547–558. URL: https://ceur-ws.org/Vol-2732/20200547.pdf.

[35] D. S. Shepiliev, Y. O. Modlo, Y. V. Yechkalo, V. V. Tkachuk, M. M. Mintii, I. S. Mintii, O. M. Markova, T. V. Selivanova, O. M. Drashko, O. O. Kalinichenko, T. A. Vakaliuk, V. V. Osadchyi, S. O. Semerikov, WebAR development tools: An overview, in: A. E. Kiv, S. O. Semerikov, V. N. Soloviev, A. M. Striuk (Eds.), Proceedings of the 3rd Workshop for Young Scientists in Computer Science & Software Engineering (CS&SE@SW 2020), Kryvyi Rih, Ukraine, November 27, 2020, volume 2832 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2020, pp. 84–93. URL: http://ceur-ws.org/Vol-2832/paper12.pdf.

[36] L. F. Panchenko, H. O. Korzhov, A. O. Khomiak, V. Y. Velychko, V. N. Soloviev, Social dimension of higher education: definition, indicators, models, in: A. E. Kiv, S. O. Semerikov, M. P. Shyshkina (Eds.), Proceedings of the 9th Workshop on Cloud Technologies in Education, CTE 2021, Kryvyi Rih, Ukraine, December 17, 2021, volume 3085 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2021, pp. 124–138. doi:10.55056/CTE.108.

[37] T. A. Vakaliuk, V. V. Osadchyi, O. P. Pinchuk, From the digital transformation strategy to the productive integration of technologies in education and training: Report 2023, in: T. A. Vakaliuk, V. V. Osadchyi, O. P. Pinchuk (Eds.), Proceedings of the 2nd Workshop on Digital Transformation of Education (DigiTransfEd 2023) co-located with 18th International Conference on ICT in Education, Research and Industrial Applications (ICTERI 2023), Ivano-Frankivsk, Ukraine, September 18-22, 2023, volume 3553 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2023, pp. 1–8. URL: https://ceur-ws.org/Vol-3553/paper00.pdf.

[38] V. Tkachuk, S. Semerikov, Y. V. Yechkalo, S. Khotskina, V. N. Soloviev, Selection of Mobile ICT for Learning Informatics of Future Professionals in Engineering Pedagogy, 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. 1058–1068. URL: https://ceur-ws.org/Vol-2732/20201058.pdf.

[39] V. B. Shapovalov, Y. B. Shapovalov, Z. I. Bilyk, A. P. Megalinska, I. O. Muzyka, The Google Lens analyzing quality: an analysis of the possibility to use in the educational process, 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. 117–129. URL: https://ceur-ws.org/Vol-2547/paper09.pdf.

[40] A. M. Striuk, S. O. Semerikov, The Dawn of Software Engineering Education, in: A. E. Kiv, S. O. Semerikov, V. N. Soloviev, A. M. Striuk (Eds.), Proceedings of the 2nd Student Workshop on Computer Science & Software Engineering (CS&SE@SW 2019), Kryvyi Rih, Ukraine, November 29, 2019, volume 2546 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2019, pp. 35–57. URL: http://ceur-ws.org/Vol-2546/paper02.pdf.

[41] N. Kushnir, A. Manzhula, N. Valko, Future and Experienced Teachers Should Collaborate on ICT Integration, in: V. Ermolayev, H. C. Mayr, M. Nikitchenko, A. Spivakovsky, G. Zholtkevych (Eds.), Information and Communication Technologies in Education, Research, and Industrial Applications, volume 469 of *Communications in Computer and Information Science*, Springer International Publishing, Cham, 2014, pp. 217–237. doi:10.1007/978-3-319-13206-8_11.

[42] K. Vlasenko, S. Volkov, I. Sitak, I. Lovianova, D. Bobyliev, Usability analysis of on-line educational courses on the platform “Higher school mathematics teacher”, E3S Web of Conferences 166 (2020) 10012. doi:10.1051/e3sconf/202016610012.

[43] V. Tkachuk, Y. V. Yechkalo, S. Semerikov, M. Kislova, V. Khotskina, Exploring Student Uses of Mobile Technologies in University Classrooms: Audience Response Systems and Development of Multimedia, 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. 1217–1232. URL: https://ceur-ws.org/Vol-2732/20201217.pdf.

[44] L. V. Pavlenko, M. P. Pavlenko, Using native virtualization technologies for teaching IP telephony to future IT specialists, CEUR Workshop Proceedings (2024) 23–34.

[45] L. V. Vasylieva, D. Y. Mikhieienko, I. A. Getman, Integration of laboratory equipment in remote learning environments, CEUR Workshop Proceedings (2024) 35–44.

[46] M. V. Moiseienko, N. V. Moiseienko, O. O. Lavrentieva, Developing pre-service teachers’ digital competence through informatics disciplines in teacher education programs, CEUR Workshop Proceedings (2024) 45–52.

[47] V. Y. Pazdrii, V. O. Kuprievych, Implementing business simulation games for strategic management training of educational leaders in Ukraine, CEUR Workshop Proceedings (2024) 53–62.

[48] M. V. Nehrey, L. M. Zomchak, The educational technology landscape in Ukraine, CEUR Workshop Proceedings (2024) 63–71.

[49] S. O. Semerikov, T. A. Vakaliuk, P. P. Nechypurenko, I. S. Mintii, O. V. Bondarenko, Shifting sands: analyzing trends in educational technology research published in Educational Technology Quarterly (2021-2023), CEUR Workshop Proceedings (2024) 72–82.

[50] S. S. Korniienko, P. V. Zahorodko, A. M. Striuk, A. I. Kupin, S. O. Semerikov, A systematic review of gamification in software engineering education, CEUR Workshop Proceedings (2024) 83–95.

[51] Y. V. Yechkalo, V. V. Tkachuk, K. A. Shurupova, V. M. Zinchenko, A. V. Puhach, Gamification in higher education: methodology, CEUR Workshop Proceedings (2024) 96–106.

[52] S. O. Semerikov, T. A. Vakaliuk, I. S. Mintii, V. A. Hamaniuk, O. V. Bondarenko, P. P. Nechypurenko, S. V. Shokaliuk, N. V. Moiseienko, Designing an immersive cloud-based educational environment for universities: a comprehensive approach, CEUR Workshop Proceedings (2024) 107–116.

[53] T. H. Kramarenko, O. S. Pylypenko, M. V. Moiseienko, Enhancing mathematics education with GeoGebra and augmented reality, CEUR Workshop Proceedings (2024) 117–126.

[54] V. Y. Velychko, E. H. Fedorenko, The utility of free software in teaching of mathematics, physics and computer science for pre-service teachers, CEUR Workshop Proceedings (2024) 127–133.

[55] I. V. Barkatov, V. S. Farafonov, V. O. Tiurin, S. S. Honcharuk, A. A. Lozko, V. V. Marushchenko, K. V. Korytchenko, V. I. Barkatov, R. F. Muravlyov, Interactive 3D visualizations for studying combat experiences and life cycles, CEUR Workshop Proceedings (2024) 134–142.

[56] Y. V. Yechkalo, V. V. Tkachuk, Methodical foundations and implementation strategies for virtual reality in professional training of vocational higher education students, CEUR Workshop Proceedings (2024) 143–153.