AREdu 2024: Where augmented reality meets augmented intelligence

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Abstract

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

Keywords

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

1. Introduction

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

Figure 1: AREdu 2024 logo.

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

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

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

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

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

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

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

2. AREdu 2024 committees

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3. Proceedings overview

3.1. Immersive learning environments and tools

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

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

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

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

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

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

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

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

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

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

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

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

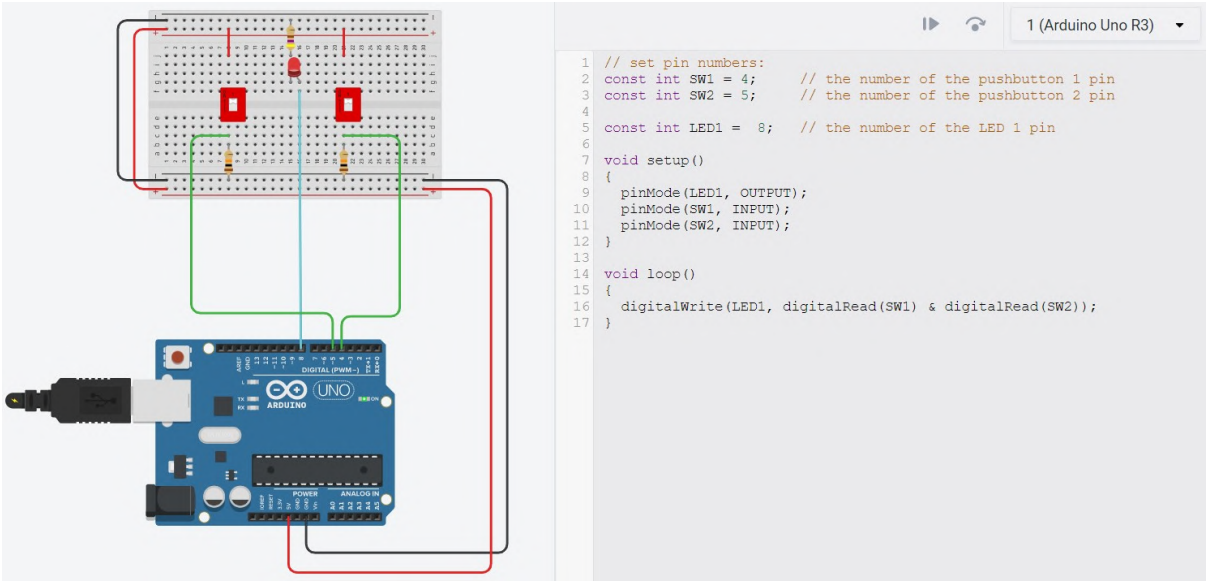

Figure 2: An example of creating a scheme for the logical operator "AND" in Tinkercad [51].

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

3.2. Augmented intelligence in education

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

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

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

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

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

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

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

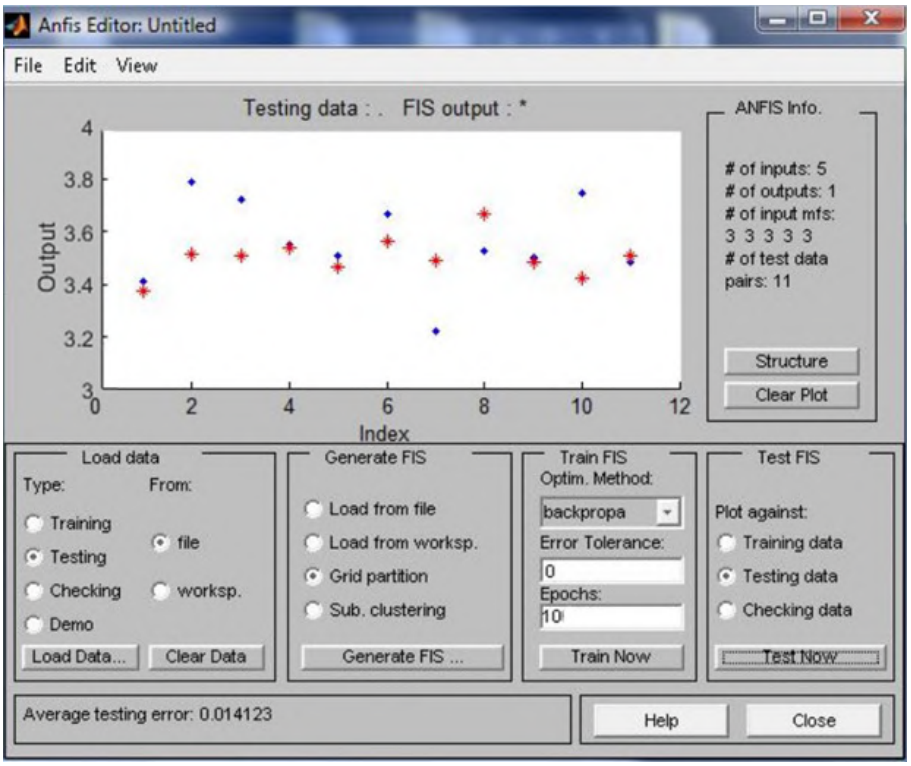

Figure 4: The results of network testing on known values of expert estimates [53].

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

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

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

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

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

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

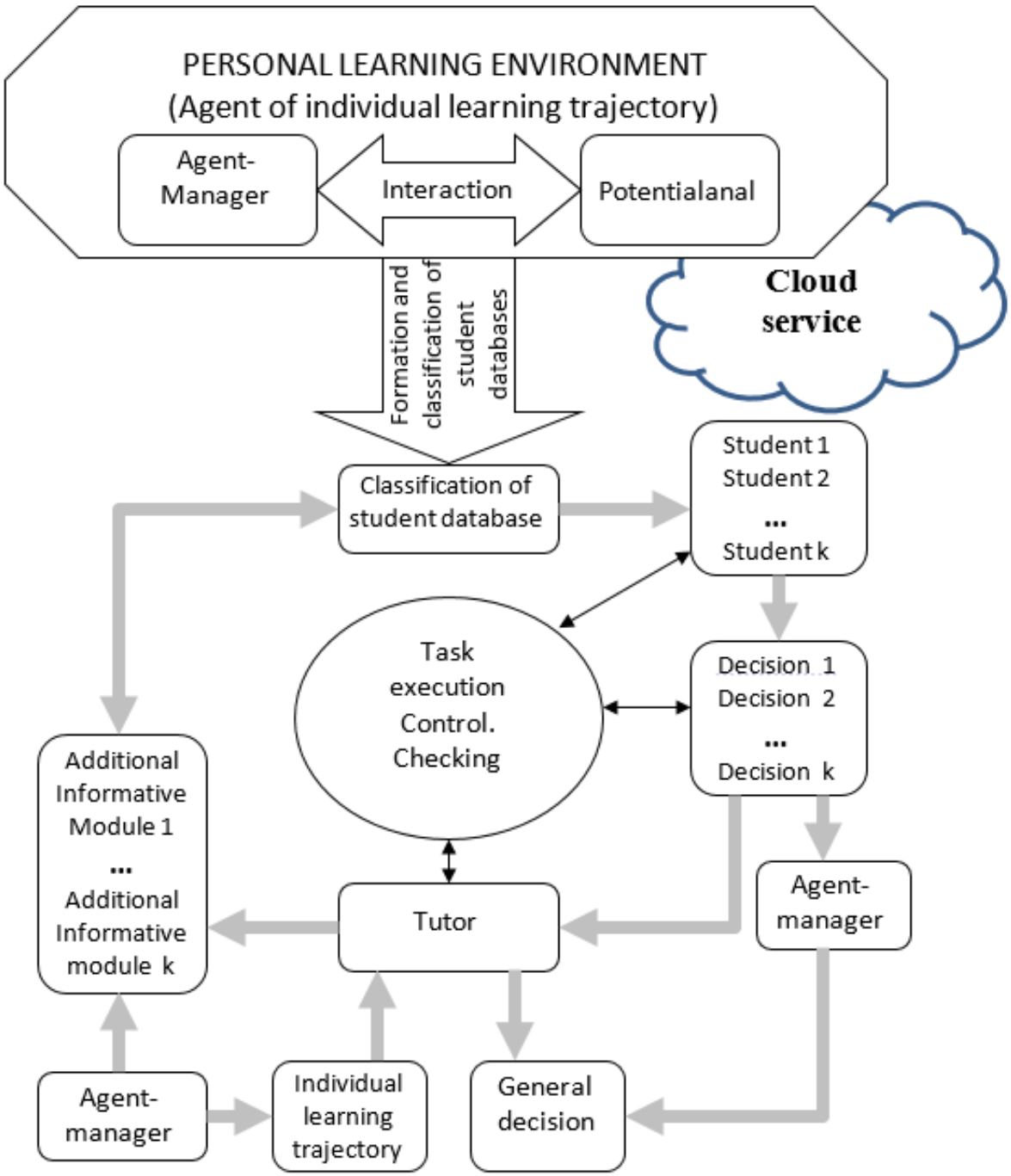

Figure 5: Flow of work of an agent-manager as part of LMS [54].

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

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

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

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

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

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

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

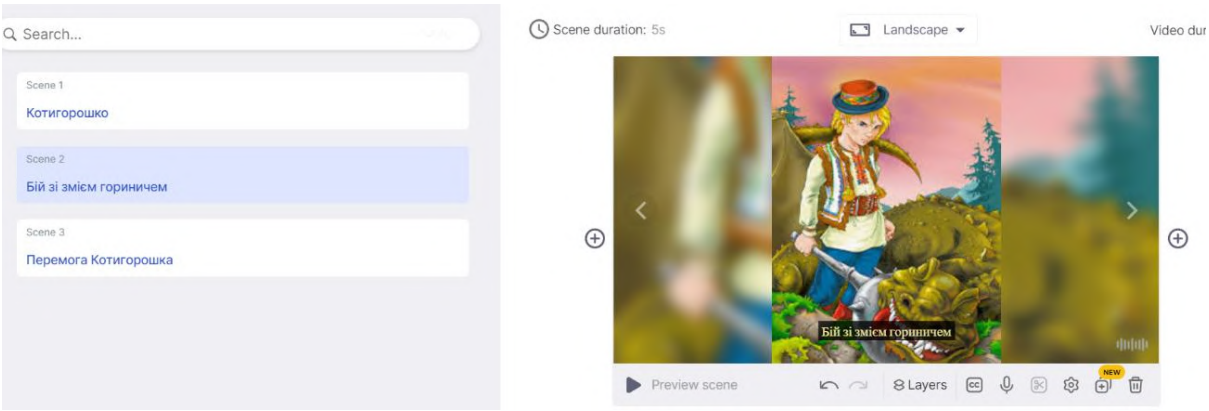

Figure 6: An example of the generation of the tale "Kotygoroshko" in the Pictory program [55].

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

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

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

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

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

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

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

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

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

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

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

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

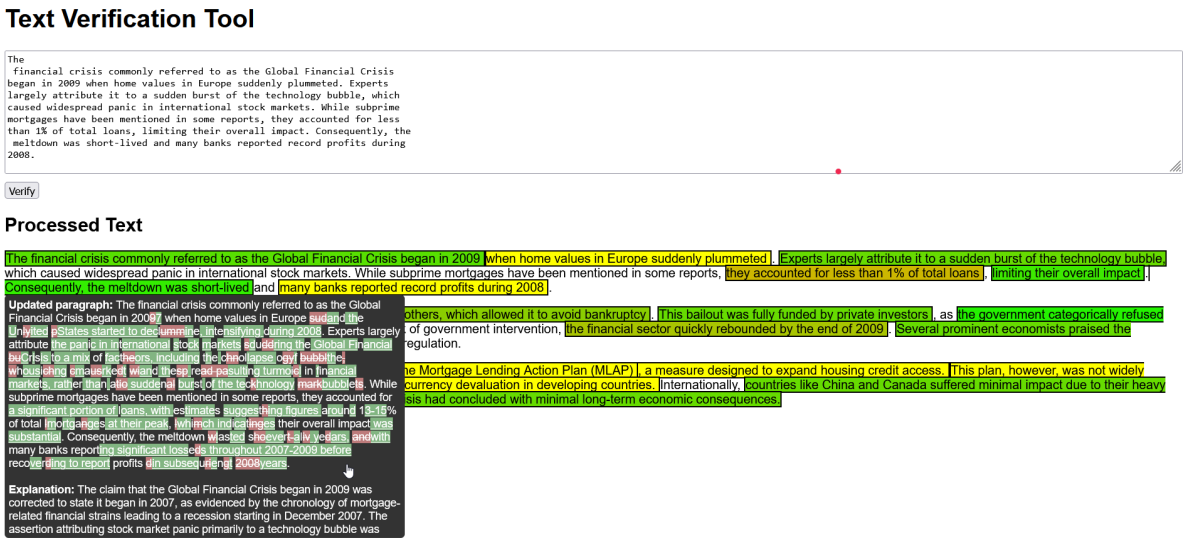

Figure 7: An example of the verification tool UI includes a field with inserted text and processed output that provides suggestions for different parts and a popup with details that are opened upon hovering highlighted parts of the text [56].

3.3. Learning analytics and educational data mining

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

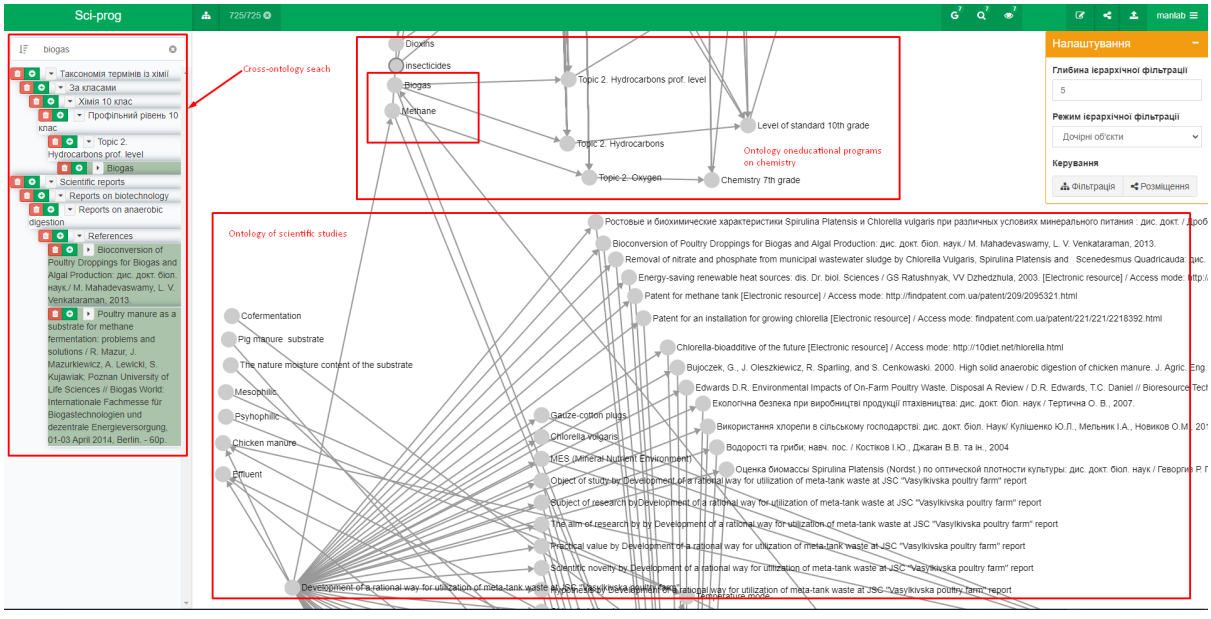

Figure 8: Using of same terms to provide interoperability between educational programmes ontology and scientific studies ontologies [57].

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

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

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

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

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

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

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

3.4. Innovative educational technologies and approaches

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

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

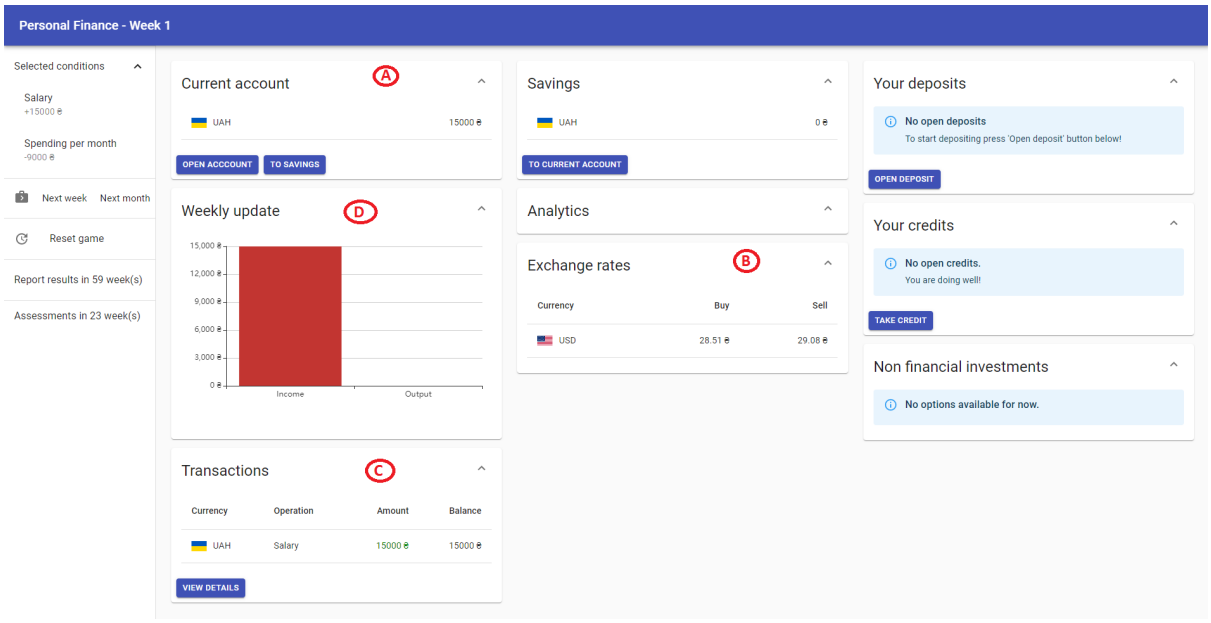

Figure 9: Business simulator [59].

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

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

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

(a) (b)

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

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

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

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

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

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

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

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

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

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

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

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

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

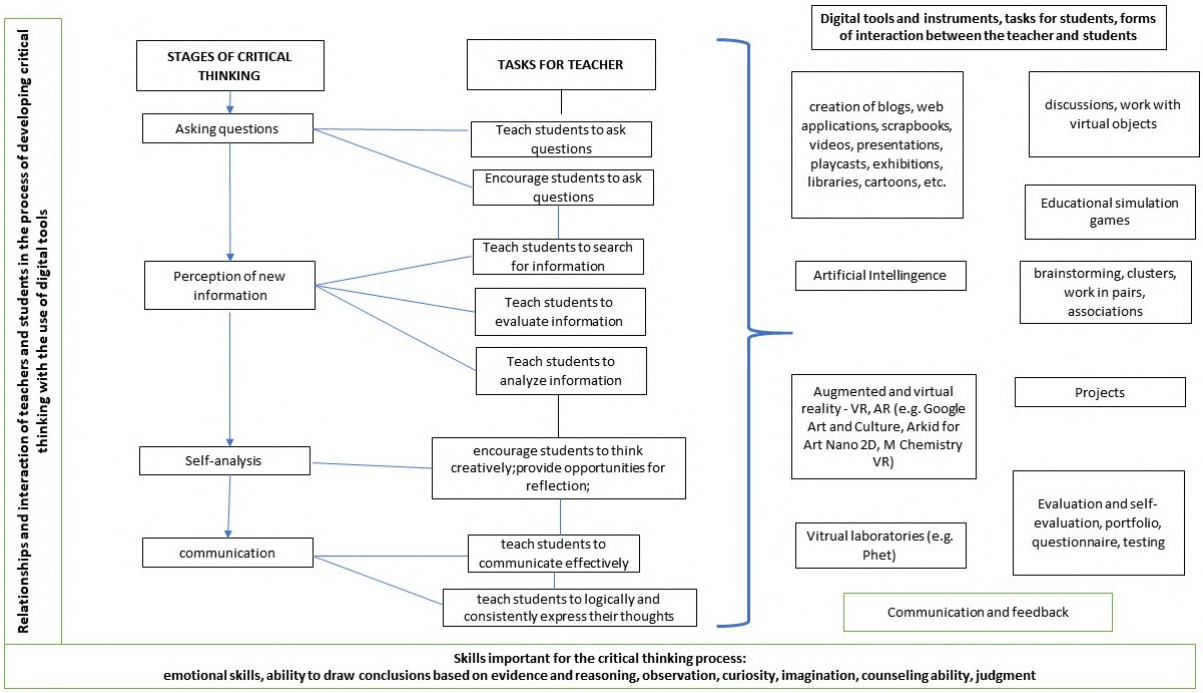

Figure 12: Relationships and interaction of teachers and students in the process of developing critical thinking with the use of digital tools [63].

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

3.5. AR/VR applications and case studies

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

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

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

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

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

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

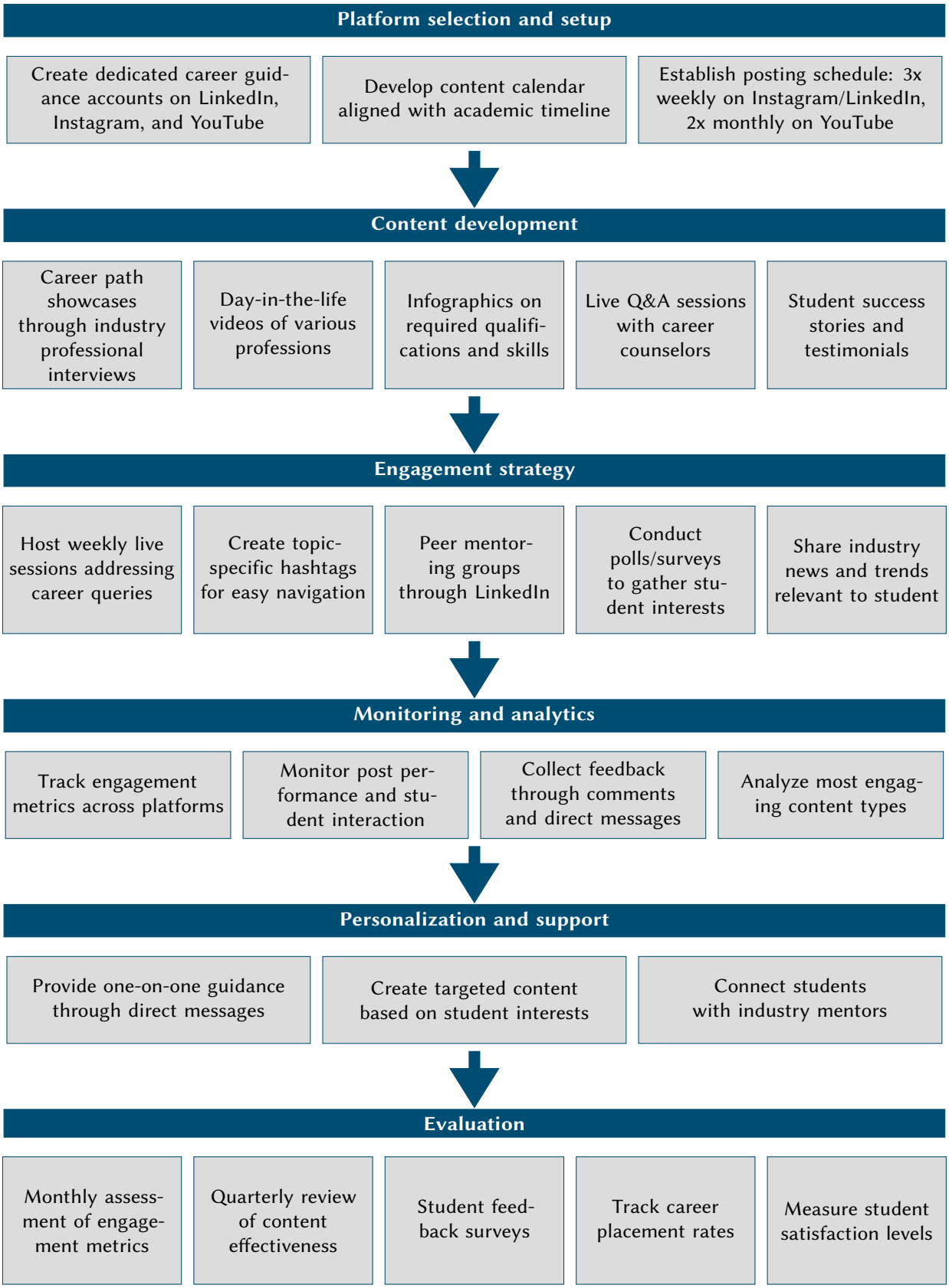

Figure 14: Implementation steps of methodology of using social media [65].

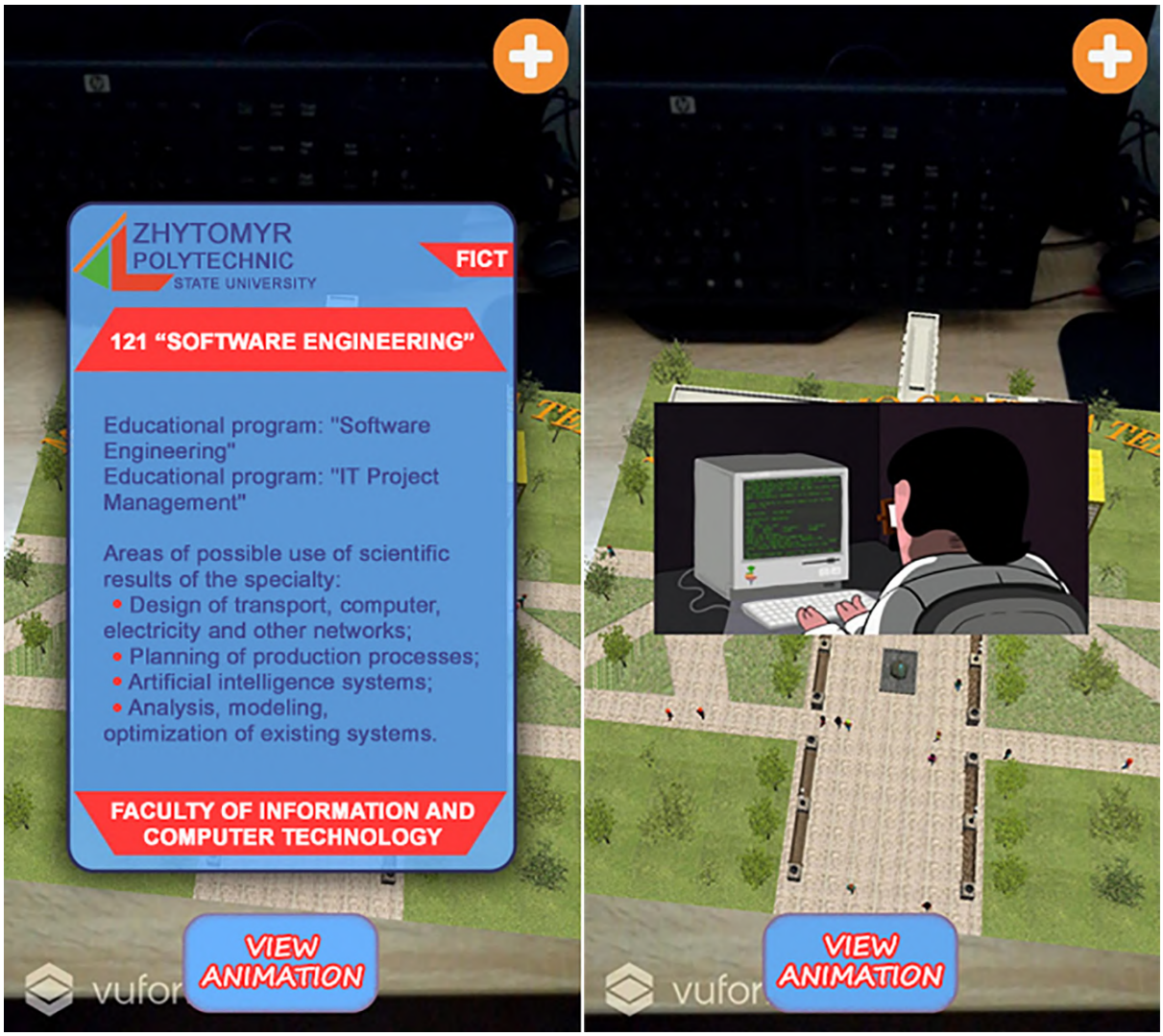

Figure 15: The result of pressing the "I" button in the mobile application [66].

considering similar initiatives.

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

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

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

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

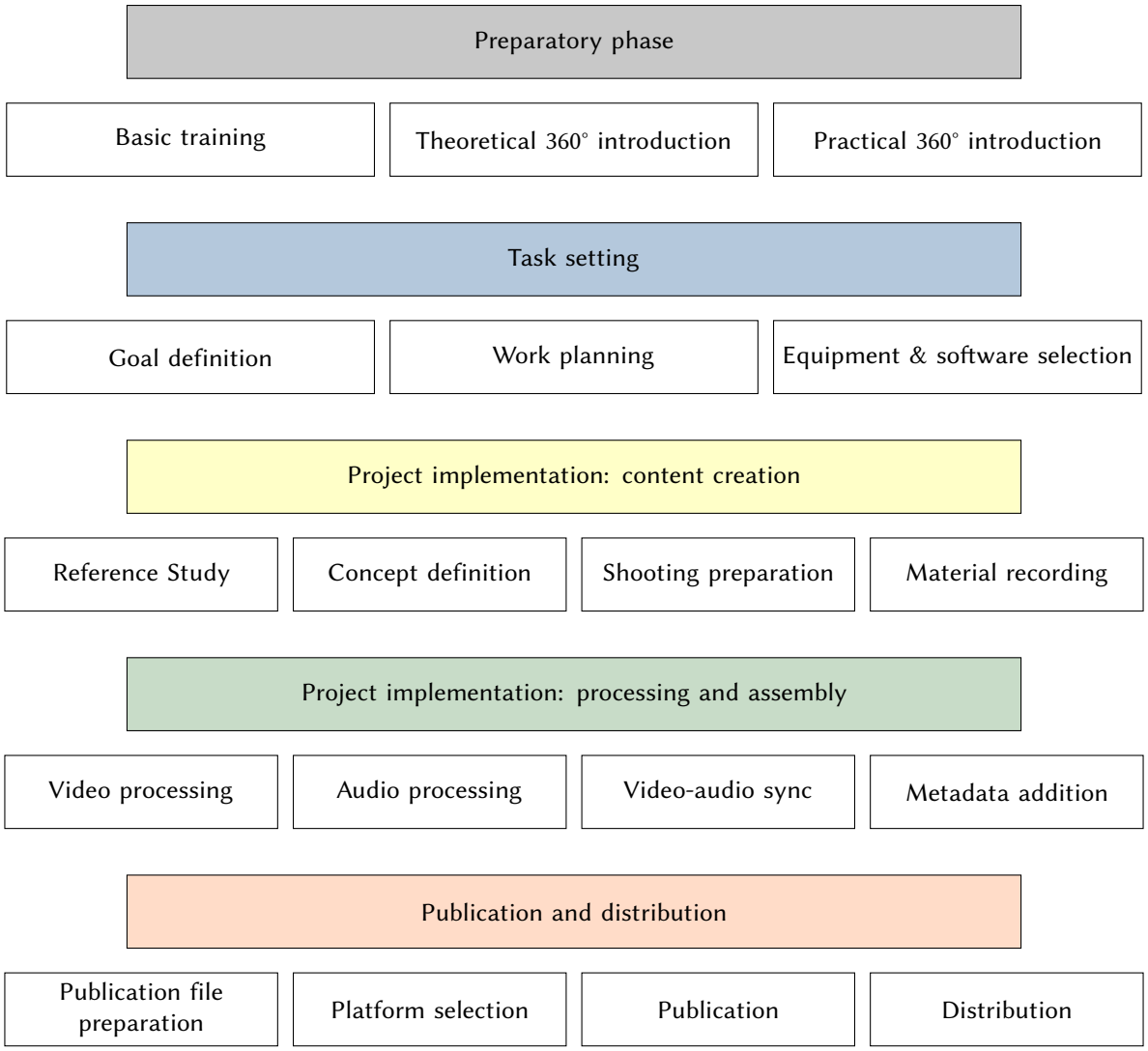

Figure 16: Stages of implementation of an educational project to create a 360° video [67].

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

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

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

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

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

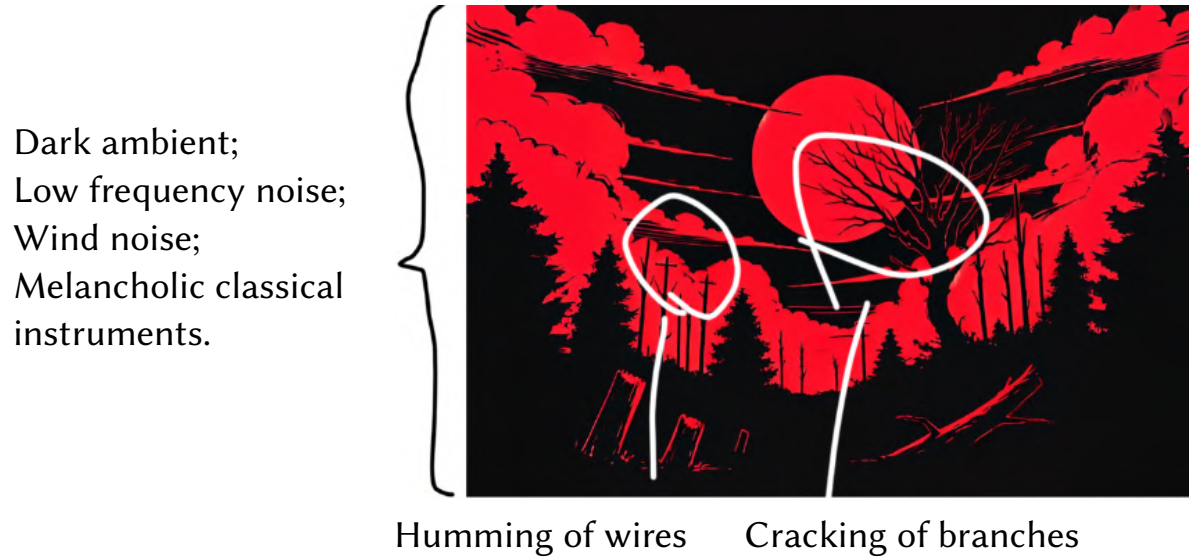

Figure 17: Determining sounds for the scene [68].

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

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

3.6. Best practices and lessons learned

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

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

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

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

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

4. Conclusion

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

The papers highlight several key trends and developments:

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

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

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

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

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

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

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

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