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Augmented reality for practice-oriented learning in dual education: a Kazakhstan case

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This study is aimed at identifying the scientific and pedagogical foundations of the integration of augmented reality, AR technologies into the system of dual vocational education and assessing their impact on the production practical and professional competencies of students. The results of a systematic analysis showed that AR technologies are an effective tool for combining theory and practice, increasing the interactivity of the educational process and forming production skills in a safe environment. Within the setting of digital transformation in the education system in Kazakhstan, it is urgent to reduce the gap between theoretical knowledge and industrial practice in dual education. From this point of view, the use of AR technologies is considered as a new pedagogical approach. The aim of the study is to develop students' competencies through the use of AR technologies in the framework of dual educational programs and to empirically evaluate its pedagogical effectiveness. The study was conducted on the basis of two organizations of technical and vocational education using a quasi-experimental method for three academic years (2023–2024, 2024–2025, 2025–2026). The experimental group used the E-dual platform.kz with AR modules, traditional training was used in the control group. The total sample consisted of $N = 410$ students ($EG = 205$, $CG = 205$). In the study, the proportion of low-performing students in both groups in all three academic years decreased by 5–7 percentage points. If in the 2025–2026 academic year the average score of the experimental group for the formative experiment was $M = 63.22$, then in the determining period the indicator was $M = 60.98$. In the control group, these indicators were $M = 60.52$ and $M = 58.78$, respectively. The growth of the experimental group was statistically higher than that of the control group ($t = 1.717$, $df = 49$, $d = 0.188$), while the growth value remained lower in the control group i.e., ($t = 1.181$, $df = 49$, $d = 0.129$). Both effective measurement values obtained on the Cohen scale refer to small impact levels.

KEYWORDS
AR-based learning models, augmented reality (AR), digital transformation, dual education, E-dual.kz platform, immersive technologies, practical skills development

1 Introduction

President of the Republic of Kazakhstan Kassym-Jomart Tokayev set the task of "turning the country into a mass digital country" within three years (Tokayev, 2025). This state policy is aimed at the radical modernization of professional and technical education. 2025 was declared the "Year of working professions" in Kazakhstan, and improving the quality of professional training and improving the dual training system was identified as a strategic priority. Within the framework of the Digital Code of the Republic of Kazakhstan, the modernization of educational infrastructure and the systematic introduction of digital technologies into the educational process are considered as integral conditions for the economic development of the country (Digital Code of the Republic of Kazakhstan, 2026). These strategic documents identify the modernization of the educational infrastructure, the expansion of the dual education model and the systematic introduction of modern digital technologies into the educational process as the main priorities. Within the framework of national policy, strengthening cooperation between educational organizations and manufacturing enterprises, as well as the formation of digital and engineering competencies necessary for the labor market, is considered as an important task. From this point of view, the introduction of augmented reality technologies into the dual education system is an effective solution that meets the goals set at the state level.

Despite the fact that at the current time there are thousands of vacancies in the country, the shortage of professional personnel is still relevant. In this regard, the development of digital and engineering competencies of working specialists has become a priority at the state level. In such conditions, the dual training system is considered as an effective mechanism for reducing the shortage of personnel by strengthening the relationship between training and production. One of the most important innovative steps in this direction is the integration of augmented reality (AR) technologies into the dual education system. AR technologies make it possible to combine educational and production processes, introduce visual and interactive teaching methods. These solutions create conditions for visualizing production processes, developing professional skills through virtual simulations and conducting distance practical training. As a result, students can master real-world production processes in a secure virtual environment and experiment with unsafe or expensive equipment. In addition, AR technologies make it possible to implement a digital version of dual learning, create virtual production environments in rural and regional colleges, as well as gain experience in digital workshops. Such innovations contribute to bringing the material and technical base of educational institutions in line with modern requirements and adapting the practical competence of students to specific production conditions.

The address of the president of the Republic of Kazakhstan in 2025 considers dual training as a key element of digital transformation and emphasizes that the integration of AR, AI and digital platforms is recognized as an important tool for improving the effectiveness of professional education. Within the framework of this parameter, several strategic measures are identified as priorities:

(1) Implementation of AR-based training simulators-the formation of professional skills of students through the use of virtual and augmented reality modules for teaching production processes—maintenance and safety rules;
(2) Updating the digital infrastructure-ensuring compliance of the educational process with modern requirements through the creation of AR laboratories, "smart" campuses and adaptive digital platforms;
(3) Improving the digital competence of teachers and developing new methodological materials - implementation of professional development programs that allow introducing innovative teaching methods in a dual format;
(4) Implementation of a system for tracking student success through the analysis of educational and production data based on AR and AI-improving the quality of education by monitoring and evaluating learning outcomes in real time.

Thus, augmented reality (AR) technologies are being systematically introduced into dual education programs today as part of a large-scale digital transformation of Education. These technologies allow not only to modernize the educational process, but also to narrow the gap between theoretical knowledge and practical experience. AR tools provide real-time guidance and create conditions for the formation of practical skills of students by correlating digital information with physical activities. The effectiveness of these technologies is especially evident in areas that require accuracy and professional skills. As a result, the integration of AR technologies in combination with the overall digitalization strategy of the country, along with improving the quality of education, is becoming an integral component of modern dual education programs.

In terms of digital transformation, the introduction of AR technologies is becoming an urgent problem, especially in the field of technical education and training. These technologies make it possible to apply innovative teaching approaches in the modern educational space, combine theory and practice, and increase the effectiveness of the dual training system. Research shows that AR technologies strengthen the relationship between educational institutions and industrial enterprises and contribute to the optimization of their activities (Yauri and Mallqui, 2024). In addition, AR technologies play a special role in the development of pedagogical and professional competencies in preparing future teachers for the learning process in the scope of digital schools. Grinshkun et al. (2021) in the study, AR technologies are considered as an important tool for the formation of innovative skills and communication competencies, and it is noted that the integration of tools such as Mind Mapping 3D and Google Lens allows you to improve the dual learning process in accordance with the requirements of digital transformation.

Augmented reality (AR) technologies create an interactive and immersive learning environment for learners that allows them to learn complex concepts in depth and effectively. Such an environment combines theoretical knowledge with practical activity, creating conditions for a conscious understanding of the subject content. Research has proven that AR tools have a

positive effect on the acquisition of practical skills by students and the development of professional competencies. In particular, Vladimirovna (2025) in his work demonstrates the effectiveness of AR technologies in practice-oriented learning, Chencheva et al. (2022) emphasizes the importance of augmented and virtual reality solutions in the formation of hard (hard) and soft (soft) skills in electrical engineering professionals. In addition, AR technologies provide the ability to present abstract concepts through real visual images. This makes it especially easy to master subjects with complex content, such as computer science and electrical engineering. In this regard, AR is considered not only as an auxiliary visual tool, but as an effective cognitive mechanism that allows the perception of educational content in a new way. The use of AR technologies in the field of vocational and dual training is of particular importance. By overlapping digital information with physical tasks, this technology facilitates real-time instruction and improves the quality of teaching in areas that require high accuracy and experience. Iyer et al. (2024) the study shows that when AR technologies are integrated into a dual learning system, students ' professional skills mature and contribute to the preservation of the acquired knowledge for a long time. In addition, the Study Stender et al. (2021) proves that AR and VR technologies effectively combine theory and practice in teaching technical disciplines, allowing the educational process to be organized more flexibly and productively. At the same time, the authors emphasize the importance of didactic approaches that take into account the personal experience and learning characteristics of students.

Digital transformation in dual education is closely related to the innovative use of virtual and augmented reality technologies. International experience shows that these technologies play an important role in improving the effectiveness of the dual education system. For example, the experience of E.ON (Kvasznicza et al., 2019) proves that the VR-based dual education model strengthens mutually beneficial cooperation between universities, companies and graduates. In addition, research shows that a number of difficulties arise in the process of implementing AR technologies. In particular, in the work (Lovcheva et al., 2019), the high technical requirements for infrastructure, the high cost of equipment and the need to train teachers for new technologies are established as the main restrictions. However, despite these obstacles, AR technologies have significant potential to improve the quality of dual education and improve the results of vocational training. They enhance the cognitive activity of students, increase motivation to learn and contribute to the long-term preservation of knowledge.

In general, augmented reality technologies are an effective tool for modernizing dual education and deepening digital transformation. AR personalizes the educational process, strengthens professional skills and closely connects the education system with production needs. Based on these theoretical and practical prerequisites, the study is structured into several interrelated sections. In the first part, the scientific foundations of the use of AR technologies in dual education are considered, in the subsequent sections, a literature review, research methodology and the results obtained are analyzed, and in the conclusion, the limitations of implementation and directions for future development are determined.

The aim of the study is to conduct an empirical assessment of the pedagogical effectiveness of the pilot AR module in the dual vocational education system in Kazakhstan and to develop a conceptual model of the E-dual educational platform.kz as the basis for scaling the AR approach.

To achieve this goal, the following tasks were set: firstly, to conduct a systematic analysis of the scientific literature on the use of AR in vocational education in accordance with the principles of PRISMA. Secondly, to develop a conceptual pedagogical model for integrating AR into dual education. Thirdly, to test the AR module in a pilot mode in real educational conditions and to assess its impact on academic results and motivation of students. Fourthly, to formulate recommendations for the full implementation of the E-dual platform.kz based on the empirical data obtained. The article is organized as follows, and the structure can be seen in Figure 1.

The Introduction section provides an introduction that reveals the relevance of the integration of AR technologies into the system of dual vocational education in Kazakhstan, the problem of the gap between theory and industrial practice is outlined, the field of the development of the platform E-dual.kz designed to unite educational organizations, students, and partner enterprises in a single digital space is described, and the purpose and objectives of the study are formulated.

The Literature Review section provides a systematic review of the scientific literature on the application of AR technologies in vocational and dual education, conducted in accordance with the principles of the PRISMA methodology. Based on the analysis of 94 sources from the Scopus, Web of Science and Google Scholar databases, existing research gaps have been identified and the choice of the research approach of this work has been justified.

The Methodology section was carried out in accordance with the principles of the PRISMA methodology, and the search for articles was carried out in databases covering the period from 2015 to 2026: Scopus, Web of Science and Google Scholar.

The Results section presents the results of a pedagogical experiment conducted over three academic years (2023–2024, 2024–2025, 2025–2026) with a total of 410 participants ($n_{EG} = 205$, $n_{CG} = 205$). For all three years, the share of low-level students in both groups decreased by 5–7 percentage points. According to the data of the 2025–2026 academic year, the effective size of the experimental group was $d_{EG} = 0{,}188$, the control group's $d_{CG} = 0{,}129$; the t-criterion value was higher in the Experimental Group ($t = 1.717$, $df = 49$), in the Control Group $t = 1.181$ ($df = 49$).

In the Discussion section, the results obtained are discussed in the field of international experience and pedagogical theory: a comparison is made with data from global meta-analyses, the mechanisms of pedagogical impact of AR in the scope of dual learning are analyzed, and the prospects for implementing the E-dual platform are substantiated.kz at the national and international level.

In the Conclusion section, the main conclusions of the study are formulated, its limitations related to the sample size and time horizon of the experiment are outlined, and the directions of further work on scaling the AR approach and the full implementation of the E-dual platform.kz are outlined in the system of technical and vocational education in Kazakhstan.

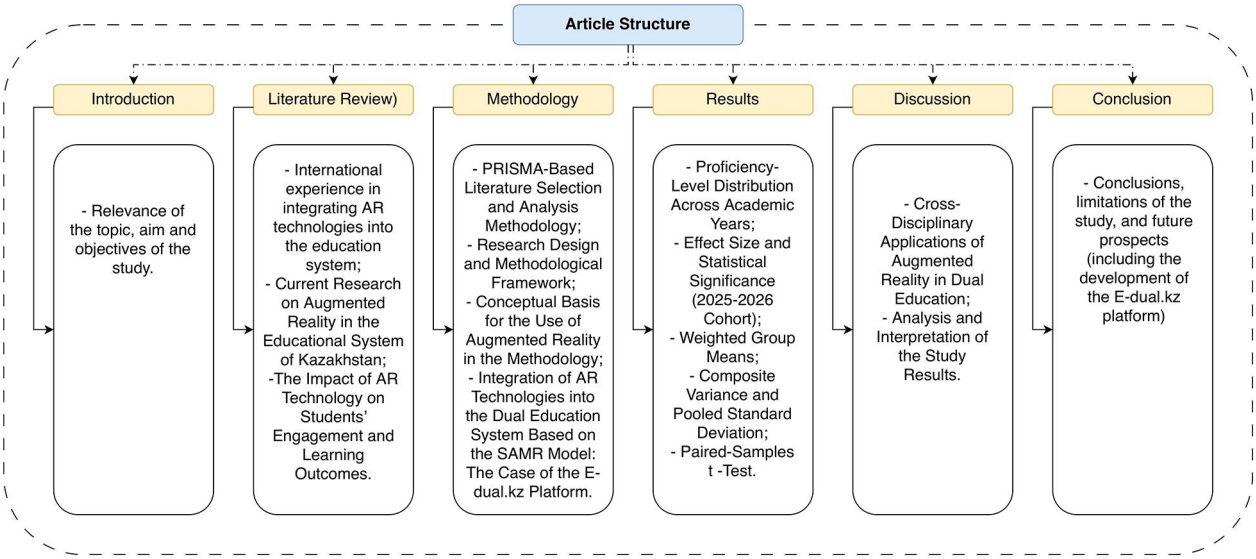

FIGURE 1
Article structure.

2 Literature review

2.1 International experience in integrating AR technologies into the education system

In recent years, augmented reality (AR) technologies have been actively used as an innovative tool in the field of Education. These technologies allow students to actively participate in the learning process and simplify the visualization of complex concepts. Complementing traditional teaching methods, AR has shown its effectiveness in improving practical skills and improving overall learning outcomes. Complementing traditional teaching methods, AR has shown its effectiveness in improving practical skills and improving overall learning outcomes. The global adoption of AR technologies varies depending on the country's investment in digital infrastructure, education policies, and technological innovation.

According to the 2025 analysis (Grand View Research, Inc., 2026), the ten countries that most actively implement AR technologies in the education system are as follows: The United States-ranked first with an AR Acceptance Index of 95%, widely used in engineering, medical and technical education, such as anatomical models and industrial simulators; China-schools and universities are implementing state programs to create AR laboratories and provide visual, interactive learning materials, reaching the 95% mark; India-90%, edtech startups such as Byju have widely implemented AR applications, providing students with affordable interactive learning materials; Japan-88%, mainly using AR in robotics and STEM disciplines; South Korea-87%, is widely implementing AR and VR tools in schools in accordance with the National Strategy "smart education"; The United Kingdom is 85%, integrating AR solutions into university virtual laboratories and practical classes; Germany-82%, uses AR solutions based on industrial modeling in professional and engineering education; Canada and Australia-80%, AR technologies play an important role in distance learning systems and teaching environmental, biological disciplines; The United Arab Emirates-78%, as part of the Smart Campus Initiative, is actively implementing AR-based learning tools in higher education institutions. In general, these indicators show that Asia (China, South Korea, Japan, India) and North America (USA, Canada) are leaders in the integration of AR technologies in educational systems (Figure 2). In these countries, the main attention is paid to digitalization policies, support for innovative startups and the development of digital competence of teachers.

Augmented reality (AR) technologies play a key role in adapting the learning process to modern educational requirements and forming students ' creative, cognitive and practical skills. The use of AR solutions in education not only improves the quality of training, but also improves the effectiveness of distance learning, laboratory work and practical training. Therefore, many developed countries consider AR technologies to be a strategic priority in the education system.

International studies have shown that AR and virtual reality (VR) technologies are used in different ways in the field of Education. For example, Ichsan et al. (2025) studied the effectiveness of using AR and VR to develop professional skills, noting that interactive practices significantly increase cognitive understanding. Bamanger (2025) the study found that AR is effective in teaching English as a foreign language (EFL), especially in increasing student activity through the visualization of vocabulary and grammatical structures. In addition, Zekeik et al. (2025) in a systematic review, the main applications of AR and VR were described as increasing student engagement, easily explaining complex concepts, and developing practical skills. Muskhir et al. (2024a) the study highlighted the innovative potential of AR/VR technologies and their role in updating educational paradigms. Thus, AR and VR are not only technological tools, but also important factors in the modernization of educational methodologies (Table 1).



FIGURE 2
Global leaders in AR education.

TABLE 1 AR applications and outcomes in different countries.

Country	Author(s)	Year	Education sector	Main results
Indonesia	Ichsan et al. (2025)	2025	Professional skills	Improved cognitive comprehension and enhanced practical skills
Saudi Arabia	Bamanger (2025)	2025	General AR education	Visualization of vocabulary and grammar and increased engagement in the learning process
Morocco	Zekeik et al. (2025)	2025	General education	Increased student interest and practical skills, along with a review of advantages and limitations
Malaysia	Muskhir et al. (2024a)	2024	Electrical engineering	Development of interactive AR modules and improved understanding of technical processes
USA	Suzuki et al. (2020)	2020	Interactive visualization	Using dynamic sketches to visualize complex concepts
South Korea	An et al. (2020)	2020	General AR education	It analyzes how AR enhances motivation, its various applications and limitations (both pedagogical and technical), noting that AR experiences are increasingly implemented in schools and universities.
Spain	López Belmonte et al. (2020)	2020	Primary/school level, government/ cooperative projects	It analyzed teachers' levels of AR implementation, digital competence, and factors influencing its adoption, noting that many initiatives require local training and support.
Turkey	Ibáñez and Delgado-Kloos (2018)	2022	Basic schools and rural learning (AR/VR projects)	Local initiatives (such as mobile AR/VR applications) have increased student engagement, while accessibility and scalability remain the main challenges
China	Zhang and Yao (2025)	2025	Science (chemistry) and school/ university	AR facilitates learning by visualizing complex concepts in chemistry and other sciences; the application is expanding, but there are pedagogical design and infrastructure requirements.
Australia	Mills et al. (2025)	2025	Higher education, support for educational texts and AR/VR	AR/VR expands the experience of reading educational materials the impact on self-study and multimodal skills; testing of pedagogical interventions is carried out.

Augmented reality (AR) technology is gaining widespread recognition in the modern educational process as an effective tool for increasing students ' motivation to learn and improving academic performance. Research conducted between 2020 and 2023 showed the importance of AR in the teaching and learning process. For example, a Nurindah et al. (2025) study showed that the use of the Assemblr Edu platform significantly increased student engagement and learning outcomes. Similarly,

Abdullah et al. (2022) the study shows that AR technology improves achievement and satisfaction in the Natural Sciences.

Augmented reality (AR) technology has become an important tool in modern education, increasing the cognitive activity of students, as well as improving the effectiveness of learning. In particular, in the pedagogical and technical fields of education, AR technology brings the learning process to a modern, interactive and practice-oriented level.

In the pedagogical sphere, AR serves as an effective tool for modernizing methods. With the help of this technology, future teachers have the opportunity to compose visual and engaging lessons. For example, primary school teachers can use AR to visualize natural phenomena or historical events in 3D, which stimulates the cognitive interest of students. In addition, in the fields of pedagogy and psychology, AR contributes to the development of students 'abilities to design learning processes, analyze the peculiarities of students' perception, and use interactive methods in practical classes. Thus, the technology will allow future educators to enrich classes with visual, game-based and experiential elements, which in turn will increase the active participation of students (Tzima et al., 2019).

In addition, AR is widely used in pedagogical laboratories, methodological trainings and pedagogical practice. This allows teachers to practically model real situations in the classroom, check lesson plans in an interactive way. Such approaches are effective in improving the professional competence, creative thinking and digital literacy of teachers.

In the Technical Direction, AR technology is widely used in the fields of Engineering, Information Technology, Construction and mechanics. Here, students can visualize and interact with complex mechanisms and structures in a realistic way. For example, in engineering disciplines, AR allows students to study 3D models of construction components, interactive analysis of electronic circuits, or modeling industrial processes. This approach contributes to the practical application of theoretical knowledge and brings the learning environment closer to real world conditions (Tuli et al., 2022). At the same time, AR increases the efficiency of laboratory work, since students will be able to conduct virtual experiments safely and without expensive equipment, as well as correct errors in real time. AR-based simulators and training systems are very effective in developing production skills, especially in the fields of robotics, electronics and automation.

However, the full implementation of AR technology in the education system still faces several challenges. Among them, an important place is occupied by the high cost of technical equipment, insufficient digital competence of teachers, as well as the weak internet and infrastructure in some educational institutions. For this reason, platforms such as eon Reality, PTC, SIEMENS and Zappar have made AR technologies accessible and user-friendly for educational purposes.

For example, the EON Reality platform offers a global solution for the use of AR, virtual (VR) and mixed (XR) reality technologies. Its main objective is to improve education and vocational training through immersive technologies, providing students with the opportunity to learn in an experiential and visual way. The platform transforms traditional learning into interactive formats, users can interact with 3D objects and conduct virtual experiments in digital laboratories. This approach combines theoretical knowledge with practical application, facilitates the understanding of complex concepts through specific examples and improves knowledge retention (Figure 3—shows the EON Reality platform model).

The Vuforia platform is a leading innovative solution developed by PTC and based on Augmented Reality (AR) technology. Its main goal is to make learning visual, interactive and practice—oriented, as well as to digitalize production and educational processes. The platform is widely used in various industries, including manufacturing, mechanical engineering, health, energy, education and services. Vuforia allows users to overlay digital information onto real physical objects. In this way, the visualization and interpretation of complex processes will be much more effective and visual. In addition, the platform is convenient for practical use and helps teachers and professionals improve educational and production processes by virtual presentation of real situations.

The platform consists of several integrated solutions:

- **Vuforia Engine** Software Development Kit (SDK) for mobile and AR devices that allows you to recognize and visualize 3d objects;
- **Vuforia Studio** authoring environment that allows users to create interactive AR lessons and learning materials without the need for programming skills;
- **Vuforia Expert Capture** a tool that records experts ' real-world knowledge and turns it into an AR-based Step-By-Step Guide for on-the-job training;
- **Vuforia Chalk** AR communication solution for distance learning and technical assistance.

Through these solutions, the Vuforia platform allows organizations to achieve several strategic goals. For example, important results can be achieved, such as improving employee training, improving operational efficiency, reducing errors, and ensuring safety in the workplace. In addition, the platform facilitates the visualization of information by interacting with real physical objects, which makes it easier to understand complex processes (Figure 4 illustrates the structure and functioning of the Vuforia platform-PTC).

Siemens Digital Industries Software (formerly known as Siemens PLM Software) is a state-of-the-art digital platform for product lifecycle and management (PLM). Its main purpose is to enable enterprises and organizations to fully digitalize the processes of product design, production, testing, maintenance and improvement. Siemens PLM solutions are widely used in various fields such as manufacturing, transportation, energy, aerospace, healthcare, mechanical engineering and education. For example, in higher education institutions, these systems are used to develop the project competence of engineering students and simulate real production scenarios (Figure 5—illustrates the structure of the Siemens Digital Industries Software platform).

Zappar is the world's leading platform for Augmented Reality (AR) and Mixed Reality (XR) technologies. Its main mission is to open up new opportunities in education, marketing and industry by creating interactive and immersive experiences. In the field of education, the Zappar platform is known as one of the most effective tools for improving the educational process. Teachers and students will be able to visually explore complex topics

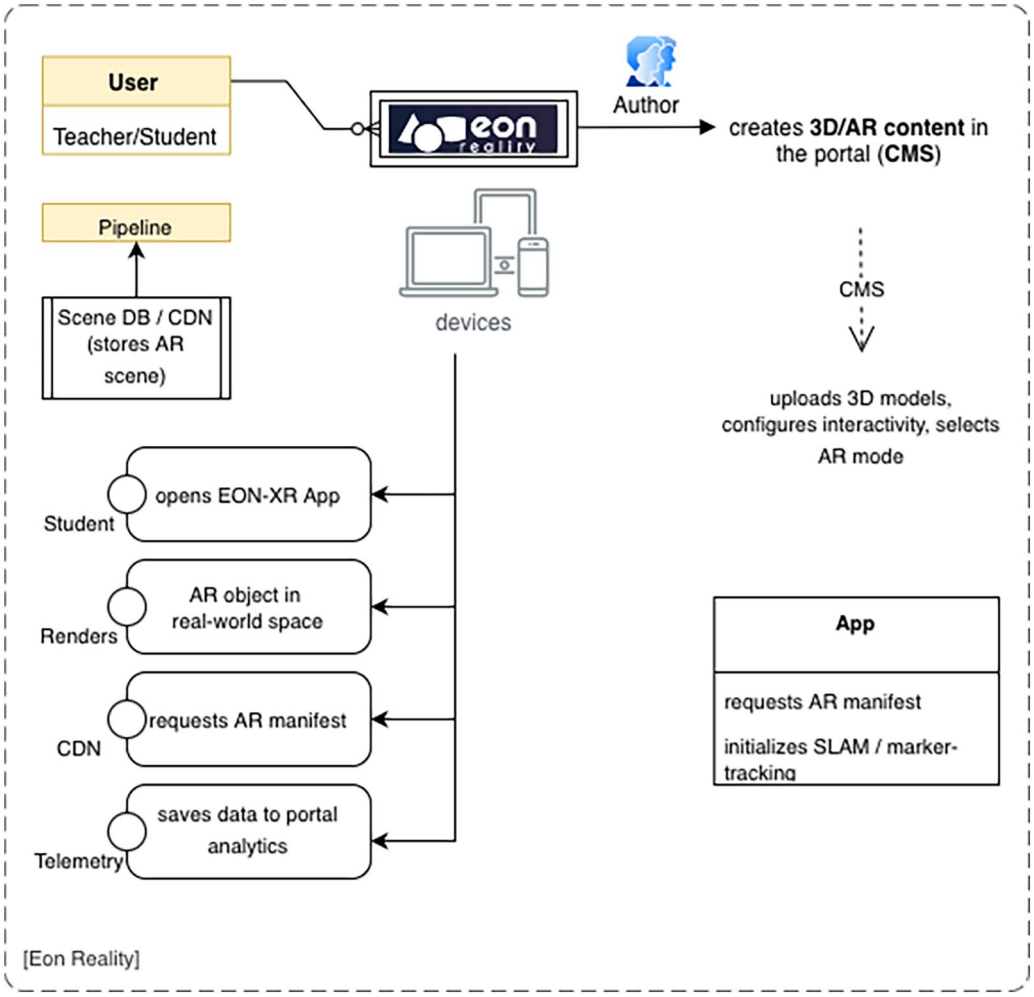

FIGURE 3
EON reality platform.

using 3d models, animations, interactive elements. Such an approach concentrates students ' attention, allows them to understand the material in depth, connects theory with practice. In addition to education, Zappar is widely used in industrial training and the development of professional skills of employees. AR-based training tools and training modules allow employees to perform tasks more efficiently, reduce errors, and improve their professional level (Figure 6 illustrates the structure and functionality of the Zappar platform).

Currently, the integration of digital technologies into the education system has become one of the main directions of improving the quality of teaching, stimulating the cognitive interest of students, and increasing the level of professional training. In particular, within the framework of the dual education system, the problem of combining theoretical knowledge with industrial practice has become particularly relevant.

2.2 Current research on augmented reality in the educational system of Kazakhstan

Along with international research, Kazakhstan scientists have also achieved significant results in this area. Arymbekov (2024) the study proved that AR-based teaching methods increase high school students understanding and motivation for Nuclear Physics topics. Mukhtarkyzy and Abildinova (2023) the study showed that the use of AR mobile applications in physics lessons significantly increases students ' learning motivation. In addition, the Rakhimzhanova et al. (2025) study found a positive effect of AR technologies on improving digital literacy of students with special educational needs in the scope of inclusive education.

In general, recent research confirms the important role of AR technology in increasing students ' interest, motivation and academic achievement in the learning process (Amores-Valencia et al., 2023). Empirical data show that AR contributes to the active participation of students in the learning process; for example, a study (Omurtak and Zeybek, 2022) found that the use of AR models in biology classes significantly increased student engagement. However, as noted in the Elford et al. (2022) study, if the complexity of AR materials does not match the level of proficiency of students, their interest and learning efficiency may decrease. In this regard, the Hsu et al. (2016) study showed that the integration of AR technology into STEAM disciplines contributes to the development of students ' critical thinking and creativity, as well as strengthening group collaboration.

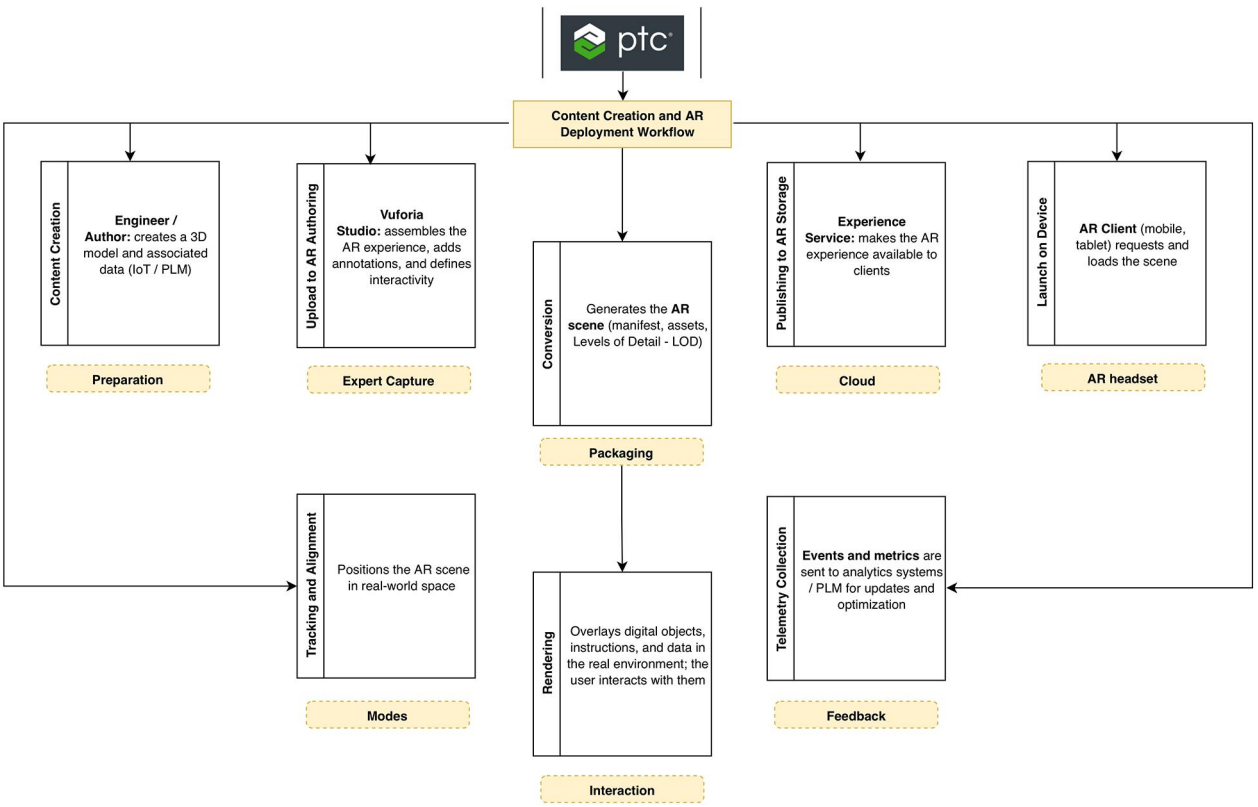

FIGURE 4
PTC platform.

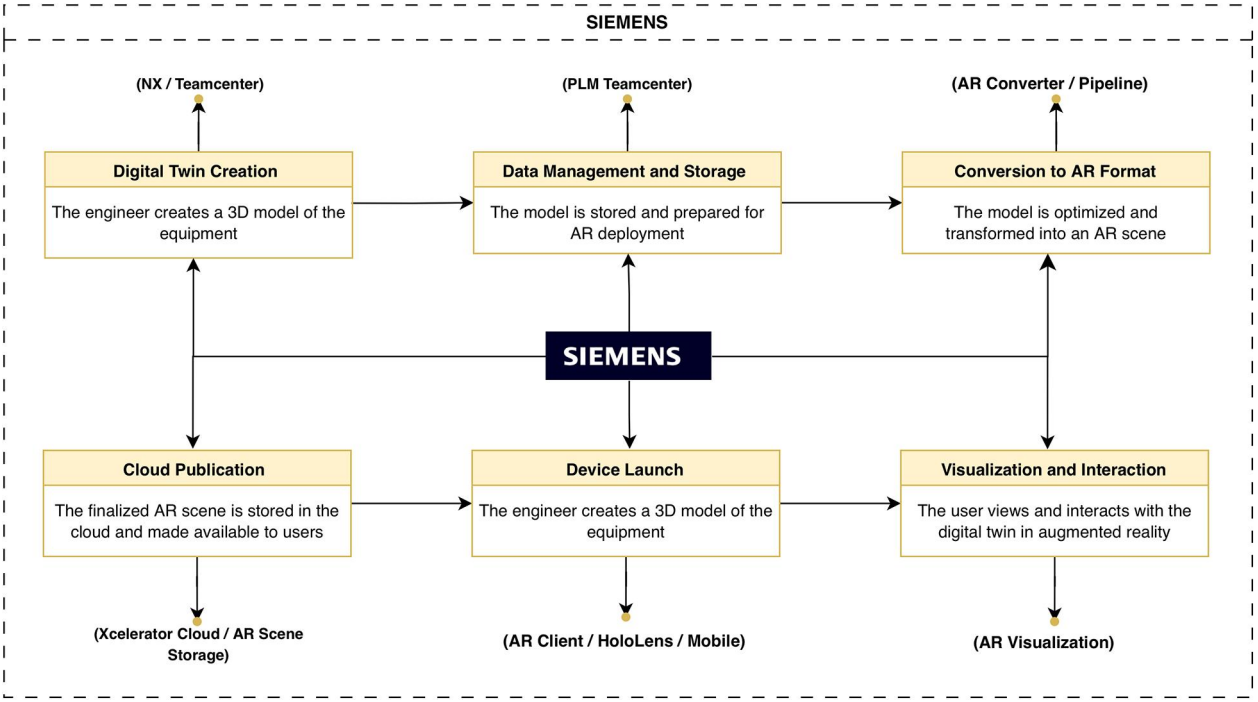

FIGURE 5
Siemens platform.

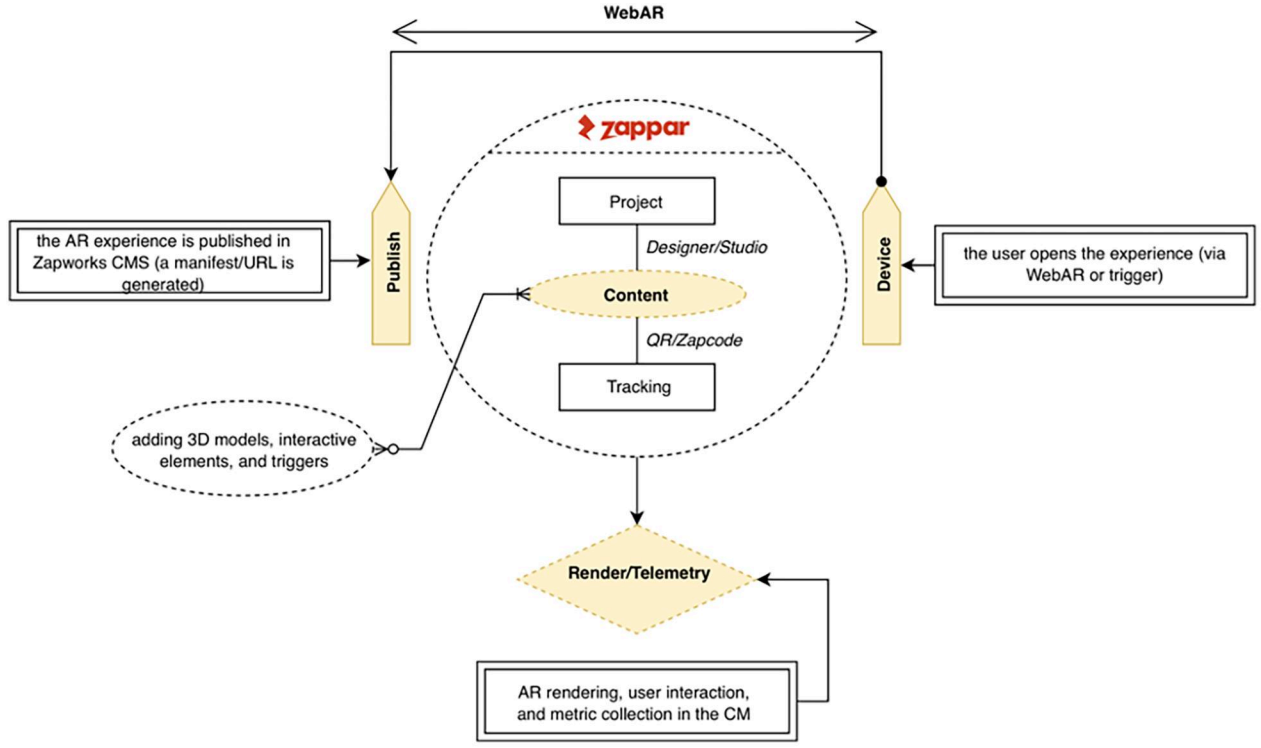

FIGURE 6
Zappar platform.

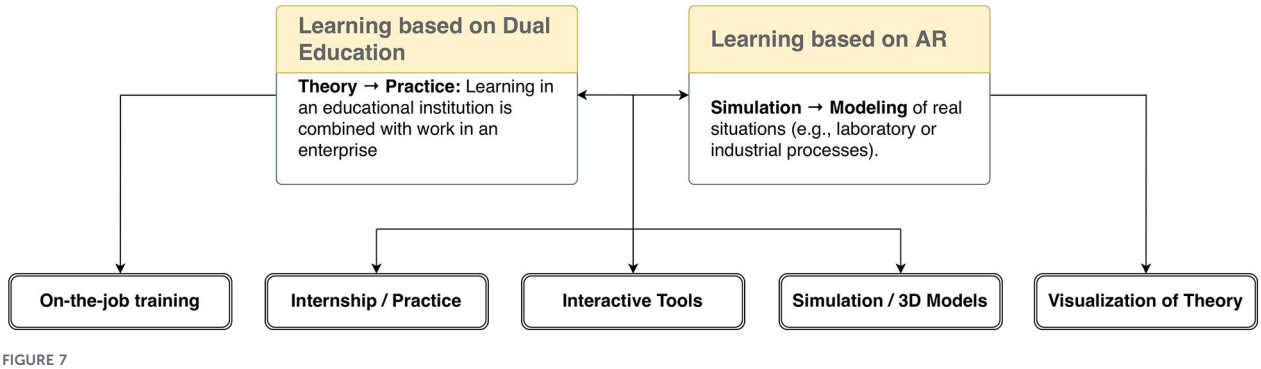

FIGURE 7
Learning based on dual education vs. AR.

The positive dynamics observed in the experimental group is directly related to the use of AR technologies in the process of dual education, and the results in the control group are explained by the level achieved by traditional theoretical education (Figure 7).

Most of the research highlights the special importance of AR technologies in the field of engineering and technical education. For example, in the work it is found that the use of augmented reality in engineering education allows students to understand more deeply through the visualization of complex structures and processes. In addition, the results of the study showed that the use of AR technologies increases the professional motivation of students and enhances their independent search activity. Similar conclusions are given in the study (Shekerbekova et al., 2025), which proves the effectiveness of integrating AR technologies into research-based learning approaches in primary education in order to improve the practical understanding of scientific concepts. Based on these scientific findings, the potential of AR technologies in improving the quality of education in engineering and Natural Sciences is revealed. This point of view is also confirmed by research aimed at the development of Science and creativity. In particular, Maina (2024) the work reveals that a learning environment based on AR technology contributes to the significant development of creative thinking in gifted students. Such a secondary education will expand the imagination of students and allow them to think outside the standard. In addition, the Wen et al. (2023) study provides a comprehensive overview of the emerging key trends in AR

technologies in education, highlighting their important role in increasing interactivity in the learning process, visual presentation of educational material, and developing experience-based learning.

Not limited to technical disciplines, the effectiveness of augmented reality (AR) technologies is being widely confirmed even in the higher education system. In particular, AlAli et al. (2025) a systematic meta-analysis covering the period 2000–2023 showed that AR technologies not only increase students ' motivation to learn, but also significantly improve their practical skills. In addition, the researchers proposed an AR-based pet care training system as an effective model that facilitates the application of practical knowledge. In the field of dual and vocational education, the importance of AR technologies is especially noticeable. The results of the interview-based study (Kamińska et al., 2023) showed that the introduction of AR and hypervideo technologies in vocational education programs contributed to the faster adaptation of students to future professional roles. In addition, it has been found that these technologies have greatly improved the level of perception of the production situation, helping to gain a deeper understanding of the real work environment. Complementing these results, bibliometric analysis (Li et al., 2024) shows that applications based on AR and VR technologies have been growing rapidly in vocational education over the past five years. These findings also coincide with a meta-analysis conducted by Candido et al. (2023) in which the positive effects of mixed reality (MR) technologies on cognitive, behavioral, and emotional outcomes were proven. At the same time, Fortuna et al. (2024) shows that the use of AR in professional certification courses increases educational sustainability and contributes to the formation of students Environmental Responsibility. Importantly, AR technologies affect not only the learning outcomes of students, but also the professional development of teachers. For example, Bödding et al. (2025) tested practical AR training programs for faculty and found that such initiatives increase the adaptability of educators to innovative technologies. In addition, the Alqahtani and Rajkhan (2020) study shows that AR technologies enhance interactivity in engineering education and strengthen the relationship between theoretical knowledge and actual industrial practice.

In general, the considered scientific research shows that augmented reality (AR) technologies are rapidly developing as pedagogical innovations in the system of dual vocational education. Works conducted in different countries and educational levels confirm that AR technologies have a significant impact on increasing learning motivation, developing practical competencies and creative abilities (Maina, 2024; Kamińska et al., 2023; Li et al., 2024). At the same time, since most of the research is focused on technological and motivational aspects, the need for additional empirical research aimed at a comprehensive assessment of the long-term effectiveness and sustainability of pedagogical models based on AR in terms of dual education remains relevant.

In this regard, as part of our research work, we aim to develop a digital educational environment that combines theoretical and practical components and is aimed at the formation of professional competence of students. Accordingly, E-dual.kz the digital educational environment shown in Figure 8 represents an innovative educational platform for digitizing the organization of dual learning and introducing augmented reality (AR) technologies into the educational process.

E-dual.kz the platform is designed to bring the dual education model to a new level in the Kazakh education system. It acts as a bridge between educational institutions, students and employers, transforming the educational process into an innovative format through the integration of AR technologies. This project will improve the quality of vocational training in the country and contribute to the formation of a modern educational ecosystem that meets the requirements of Industry 4.0.

Expanding on this scientific analysis, Table 2 presents a comparative review of the latest research on the use of advanced and virtual reality (AR and VR) technologies in the field of Education. The table covers ten scientific studies published between 2015 and 2026, systematically outlining the methods used, the technologies used, the main limitations and scientific contributions. The research covers a wide geographical range from Kazakhstan and Indonesia to the global level, testifying to the steady growth of international scientific interest in AR/VR technologies. The collected data, in addition to identifying current trends in research areas, reveal such recurring problems as technical limitations and the level of training of teachers. At the same time, the considered works demonstrate the high pedagogical potential of AR/VR tools aimed at improving the effectiveness of teaching, developing digital literacy and improving the quality of professional training.

The main goal of the study is to identify the scientific and pedagogical foundations of integrating augmented reality (AR) technologies into the educational process and prove their effectiveness in the development of cognitive, practical and creative competencies of students. To achieve this goal, the following research questions and objectives were established:

1. Analysis of pedagogical capabilities of augmented reality (AR) technologies;
2. Identification of the scientific and theoretical foundations of the integration of AR technologies;
3. Propose ways to ensure the sustainability of digital transformation through AR technologies;
4. Development of a conceptual pedagogical model aimed at introducing AR elements into the educational process.

The systematic implementation of these tasks ensures the integrity of the study and makes it possible to comprehensively describe the scientific foundations of the introduction of AR technologies into educational practice.

2.3 The impact of AR technology on students' engagement and learning outcomes

Augmented reality (AR) technologies, combining elements of the real and virtual world, increase students ' interest in the learning process, strengthen motivation, and allow a deeper understanding of the material. This approach creates a dynamic and adaptive learning environment, and numerous studies confirm the growing interest in using AR to improve

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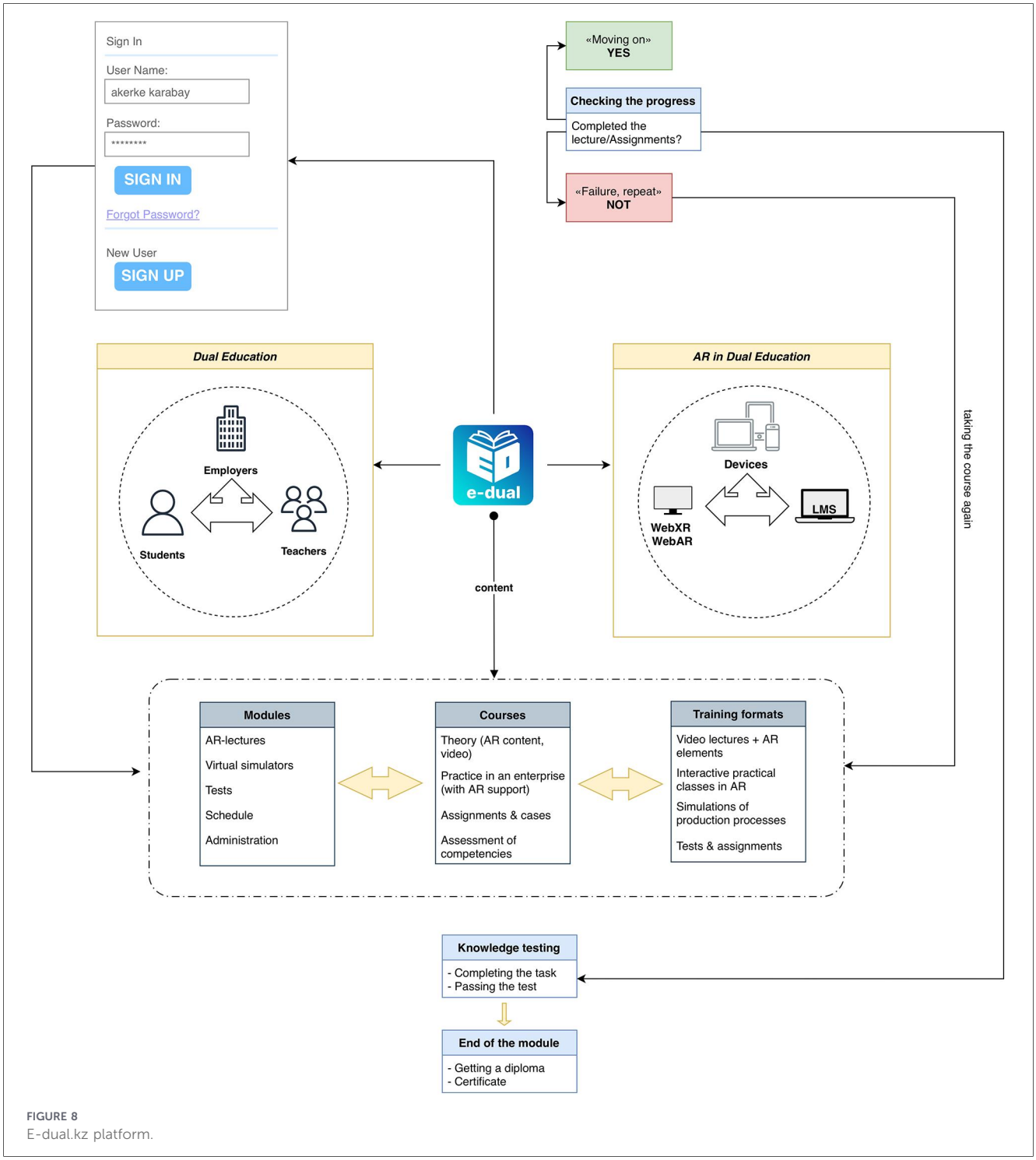

FIGURE 8
E-dual.kz platform.

professional development by combining theoretical and practical learning.

The main advantages of using AR technology in education are a significant increase in student activity, effective acquisition of skills, and increased motivation in various professional situations. However, research has also identified several problems that hinder the widespread use of the technology. Table 3 shows the main restrictions that prevent the implementation of AR technologies in dual and vocational education systems.

First of all, the main problem is the lack of equipment and infrastructure. Tools such as smartphones, tablets, cameras and high-speed internet are not equally available in all educational institutions. This limits the ability for students and teachers to make full use of AR modules.

In addition, insufficient technical training of teachers prevents the effective integration of AR technologies. In such a situation, educators may abstain from using new tools, which will negatively affect the quality of learning. Another urgent problem is the insufficient inclusion of AR educational material in the

TABLE 2 Research on AR/VR technologies in education.

Authors	Region covered	Methods	Technologies	Key limitations	Main contributions
Uderbayeva (2024)	Kazakhstan	Experimental Research	Virtual & augmented reality (VR/AR)	Limited technical resources in schools	Improving computer science teaching
Issabayeva (2025)	Kazakhstan	Case study	Augmented Reality	Accessibility barriers for special-needs learners	Enhancing digital literacy skills
Akhmetova (2024)	Kazakhstan	Pedagogical experiment	Virtual Reality	Lack of teacher preparation	Advancing ESP teaching effectiveness
Zenkina (2024)	Kazakhstan	Applied research	Augmented Reality	Curriculum integration issues	Promotion of STEM education
Kazlaris et al. (2025)	Global	Systematic review	Augmented Reality	Fragmented evidence base	Insights into collaborative learning
Ramadhan et al. (2024)	Indonesia	Trend analysis	Augmented Reality	Insufficient alignment with workforce needs	Skill development in vocational education
Bacca et al. (2015)	Global	Experimental design	Mobile Augmented Reality	Hardware limitations	Practical use in vocational training
Garzón (2021)	Global	Overview study	Augmented Reality	Lack of longitudinal evaluation	Historical synthesis of AR research
İspir et al. (2024)	Indonesia	Quasi-experimental	Augmented Reality	Measuring long-term learning effects	Improved informatics learning outcomes
Vanga (2024)	Global	Conceptual analysis	AR & VR	Ethical and pedagogical challenges	Future perspectives on immersive education

TABLE 3 Factors hindering the implementation of AR technologies in dual and vocational education.

Limitation	Description	Consequences	Future direction	Author
Equipment and infrastructure limitations	AR requires smart devices and high-speed internet, often limited in DE institutions	Restricted AR use lowers teaching quality	Upgrade infrastructure, support low-spec AR, add offline functions	Akçayır and Akçayır (2017)
Low technical training of teachers/mentors	AR implementation requires skills not always provided	Slow AR adoption limits benefits	Develop accredited AR pedagogy programs	Tian and Ironsi (2025)
Insufficient subject matter and pedagogical integration	AR modules may not align with curricula and assessments	Disconnected AR use reduces educational impact	Integrate AR in curricula, link to assessments, develop guidelines	Albishri and Blackmore (2024)
Uncertain long-term effect	Most studies are short-term; long-term impact unknown	Unclear ROI slows adoption	Conduct long-term studies and scaling strategies	Chang et al. (2025)
AR device limitations	Head-mounted devices expensive; adaptation slow	Interactivity and realism limited	Improve AR interfaces; hybrid learning	Blattgerste et al. (2021)
Lack of standardization	AR devices/platforms lack compatibility	Implementation inconsistent and limited	Develop AR pedagogical frameworks	Hajirasouli and Banihashemi (2022)
Instability of AR devices; internet addiction	Motivation and engagement vary	Teacher low competence reduces effectiveness	Create collaborative learning scenarios	Piedade and Batista (2025a)
Self-report bias	Teachers rated AR highly in self-reports	Acceptance–confidence gap limits effective use	Adapt training via TPACK; validate experimentally	Piedade and Batista (2025b)
Hardware limitations	Scope limited by low equipment and readiness	Obstructs widespread AR adoption	Integrate AR with databases, enhance interaction	Iqbal et al. (2021)
iOS incompatibility	Pilot AR model shows technical issues	Headset discomfort; disrupted keyboard interaction	Ensure cross-platform compatibility	Parekh et al. (2020)

curriculum and pedagogical methodology. In most cases, AR modules are used only as an additional element, not systematically integrated into the educational process. As a result, students ' learning experience loses continuity and the potential of technology is not fully used.

There are also several limitations on the technical side: unstable performance of devices, internet addiction, incompatibility on different platforms (for example, iOS and Android), as well as the high cost and limited availability of devices. All these factors slow down the large-scale implementation of AR solutions in education.

The diversity of methodological approaches used in studies and differences in the quality of evidence limit the generalizability of results. Moreover, organizational and infrastructural barriers have not been sufficiently explored. Consequently, current research highlights the need to develop reliable, scalable, and context-adaptive integration strategies to fully realize the educational potential of AR technologies. However, effective implementation of AR technologies in educational institutions requires a thorough analysis of pedagogical models and adaptation to specific pedagogical frameworks in order to maximize their potential.

In dual and vocational education, augmented reality (AR) technologies provide a promising model for enhancing interactivity, visualization, and practical skills. The introduction of AR technologies creates a comprehensive learning environment that reduces the gap between theoretical knowledge and practical application, contributes to the development of skills and long-term preservation of knowledge. In conclusion, AR technology in dual education has several main advantages: a clear and visual presentation of educational materials, high-cost modeling of production processes and equipment, and encouraging student participation in interactive activities. Through these, professional thinking and decision-making skills are developed. In addition, AR technology can also be used effectively in the distance learning format, facilitating personalized learning.

However, the introduction of AR technologies in dual education faces several limitations and challenges. Their development and adaptation requires significant financial investments and technical resources. Insufficient digital competence and methodological training of instructors reduces the effectiveness of AR tools. In some educational institutions, weak material and technical infrastructure and limited access to the internet hinder the widespread use of technologies. Updating curricula and adapting pedagogical methods to the AR environment requires long-term efforts and institutional support.

From a technological point of view, the development of motion control, voice control and AR platforms will make the learning process more interactive and accessible. However, the high cost of equipment and weak infrastructure hinder large-scale use. Although methodological aspects are characterized by an increase in mixed learning methods and systematic reviews, small samples and short-term studies limit the reliability of the results (Figure 9).

In terms of technological integration, combining AR technology with artificial intelligence (AI) and Mixed Reality (XR) solutions increases learning bias, but ethical and privacy issues remain relevant. While ethical and legal issues affect students ' digital literacy, data protection and privacy issues

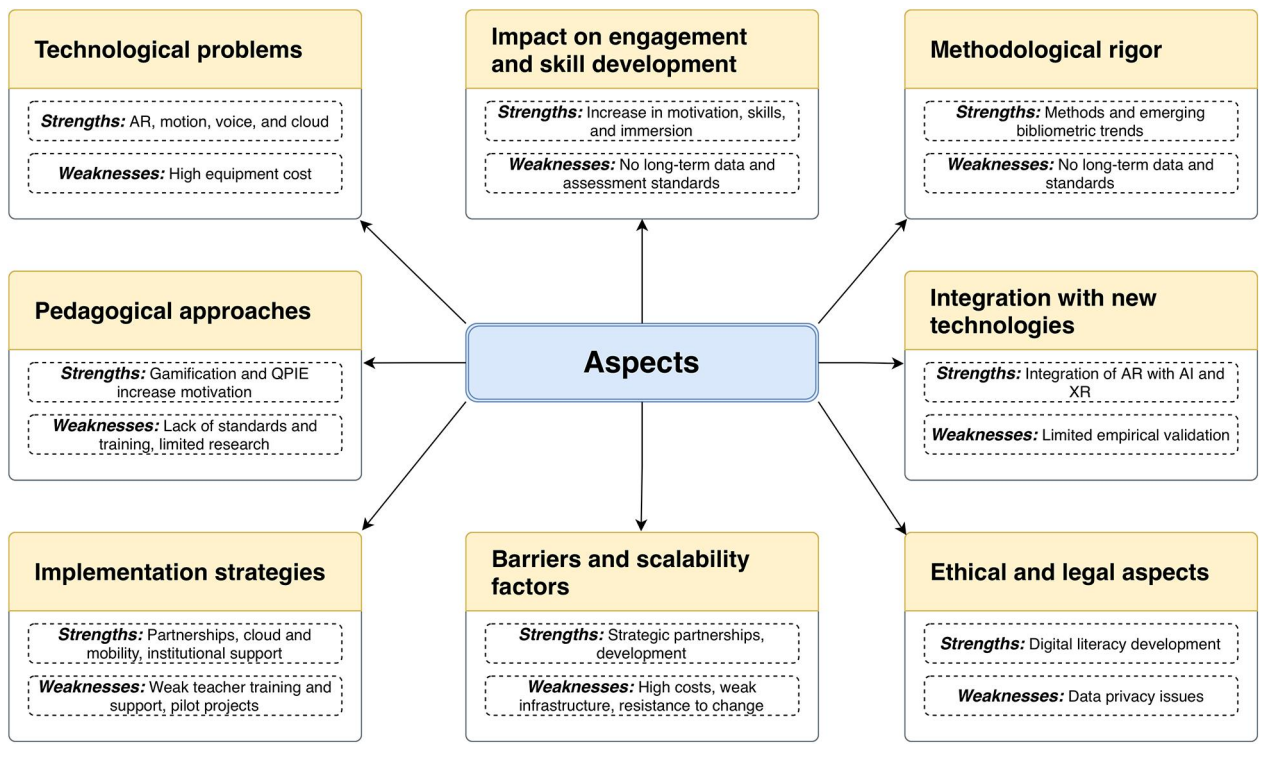

FIGURE 9
Comprehensive overview of aspects.

require additional attention. In conclusion, the dual education system is an effective, practice-oriented model integrated with modern technologies. However, its widespread implementation requires the improvement of pedagogical, technical and legal infrastructure, as well as a high level of professional training and institutional support of teachers.

In general, AR technology makes it possible to update the dual learning material and bring the integration between theory and practice to a new level. To achieve real and successful results in this area, it is necessary to strengthen the partnership between educational institutions and industry, improve the professional skills of teachers and improve the technical infrastructure. And only thanks to this systematic and integrated approach, AR technology can qualitatively bring dual education to a new level.

3 Methodology

3.1 PRISMA-based literature selection and analysis methodology

To ensure reproducibility and transparency of literature analysis was conducted in accordance with the principles of the PRISMA methodology (Farrús, 2023). The search was carried out in three databases: Scopus, Web of Science and Google Scholar-and covered the period from 2015 to 2026. The following keyword combinations were used: "augmented reality", "AR learning", "vocational education", "dual education", "digital learning technologies", "AR in professional training". An initial search revealed 312 publications. After deleting the duplicates, 248 sources remained. The application of inclusion criteria-compliance with the subject of vocational or dual education, the availability of empirical data, the availability of the full text, publication in a peer-reviewed publication - reduced the sample to 94 papers, which formed the final array for detailed analysis. The exclusion criteria were: the lack of a learning environment, the use of AR exclusively for marketing or entertainment purposes, as well as work without a clear description of the methodology. The methodological basis of the study includes the following approaches (Figure 10).

The research methodology includes six main approaches to conducting a comprehensive analysis of the integration of augmented reality (AR) technologies into the education system. First, a systematic review of the literature (Muskhir et al., 2024b) was carried out with the aim of identifying the role of AR technologies in education and forming their theoretical foundations. Secondly, the methods of textual analysis and classification were used to systematize research areas, identify areas of application of AR and differentiate the main trends in the field of Education. Thirdly, conceptual modeling (Kurniawan et al., 2024) is used to structure the principles of visualization and Interactive modeling, which served as the basis for the development of an AR-based learning model. Fourth, the pedagogical experiment (Little et al., 2021) was aimed at empirically verifying the effectiveness of the proposed model and evaluating its impact on student learning outcomes. Fifth, qualitative analysis (Nakazawa et al., 2023) made it possible to study the perception, motivation and attitude of students to AR technologies in the educational process. Sixth, practical teaching methods (Lampropoulos et al., 2025) have been used to improve the professional skills of teachers and ensure the effective integration of AR technologies into pedagogical practice. The combination of these six approaches will strengthen the scientific validity of the study and make it possible to comprehensively assess the effectiveness of AR technologies in the education system. In addition, the combination of methods increases the reliability of the results obtained and ensures the triangulation of the data.

The interconnection of these six methods strengthens the scientific validity of the research and allows for a comprehensive demonstration of the effectiveness of AR technologies within the education system. The combination of these approaches enhances the validity and reliability of the findings and ensures data triangulation.

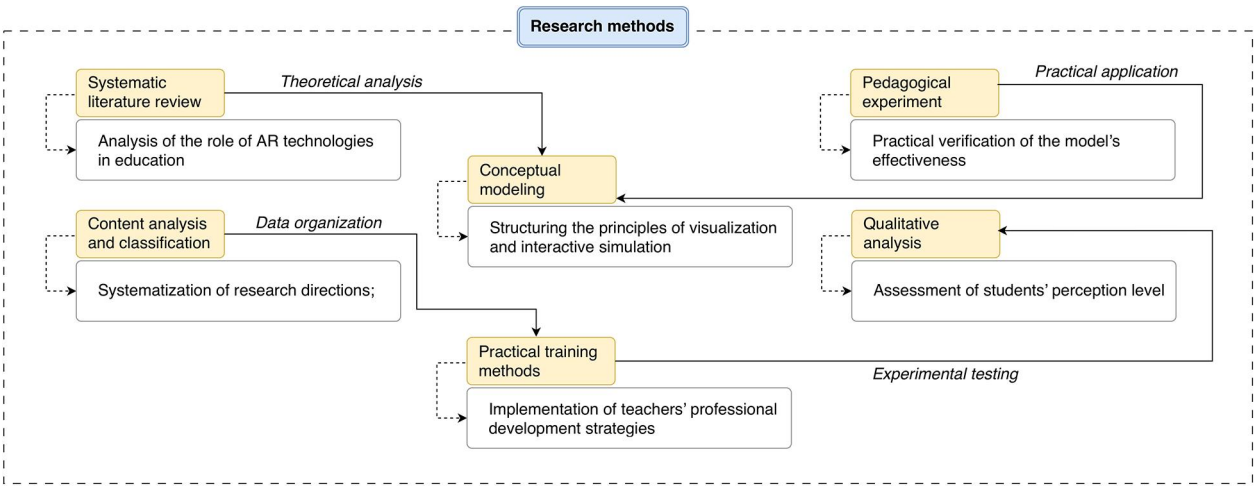

FIGURE 10
Study methods and approaches.

3.2 Research design and methodological framework

The research process consists of several interrelated stages, each building upon the results of the previous one to maintain a coherent scientific logic. The structure and current status of the research methodology are summarized in Table 4, which systematizes the main stages, objectives, methods, and implementation levels.

The proposed methodology reflects the step-by-step structure of the study, in which each stage is logically connected with the previous one and is aimed at forming the scientific basis for integrating augmented reality (AR) technologies into the educational process.

Augmented reality (AR) technology makes the learning process immersive and interactive, allowing the visualization of complex concepts and the development of practical skills in a safe and controlled environment (Figure 11).

3.3 Conceptual basis for the use of augmented reality in the methodology

Immersiveness describes the student's sense of full involvement in a virtual or extended environment. This allows students to perceive the teaching material in a spatial and realistic way, making them active participants in that environment (Alhebaishi and Stone, 2024). And interactivity refers to the level of interaction between the user and digital learning resources. The student does not passively perceive information, but actively interacts with digital objects and performs tasks, which makes it possible to form an active

TABLE 4 Research methodology framework.

Stage	Objective	Method approach	Key activities	Current status	Reference
Literature Review	To analyze existing AR studies and identify educational gaps	Systematic qualitative synthesis	Review and thematic classification of AR research	Completed	Belani and Parnami (2020)
Model Development	To design a conceptual AR integration model for education	Case-based and conceptual modeling	Development of framework and visualization modules	In Progress	IEEE (2022) and Lee and Hsu (2021)
Experimental Phase	To evaluate the proposed AR model's effectiveness	Quantitative (pre/post testing planned)	Designing instruments and preparing pilot testing	Planned	Kurakbayeva and Xembayeva (2025)
Qualitative Validation	To assess learners' engagement and perceptions	Focus-group interviews, observation	Development of questionnaires and interview protocols	Planned	Tan et al. (2022)
Instructor Training	To enhance educators' AR integration skills	Workshops and professional development sessions	Planning of AR teaching seminars	Planned	Aghapour and Bockstahler (2022)

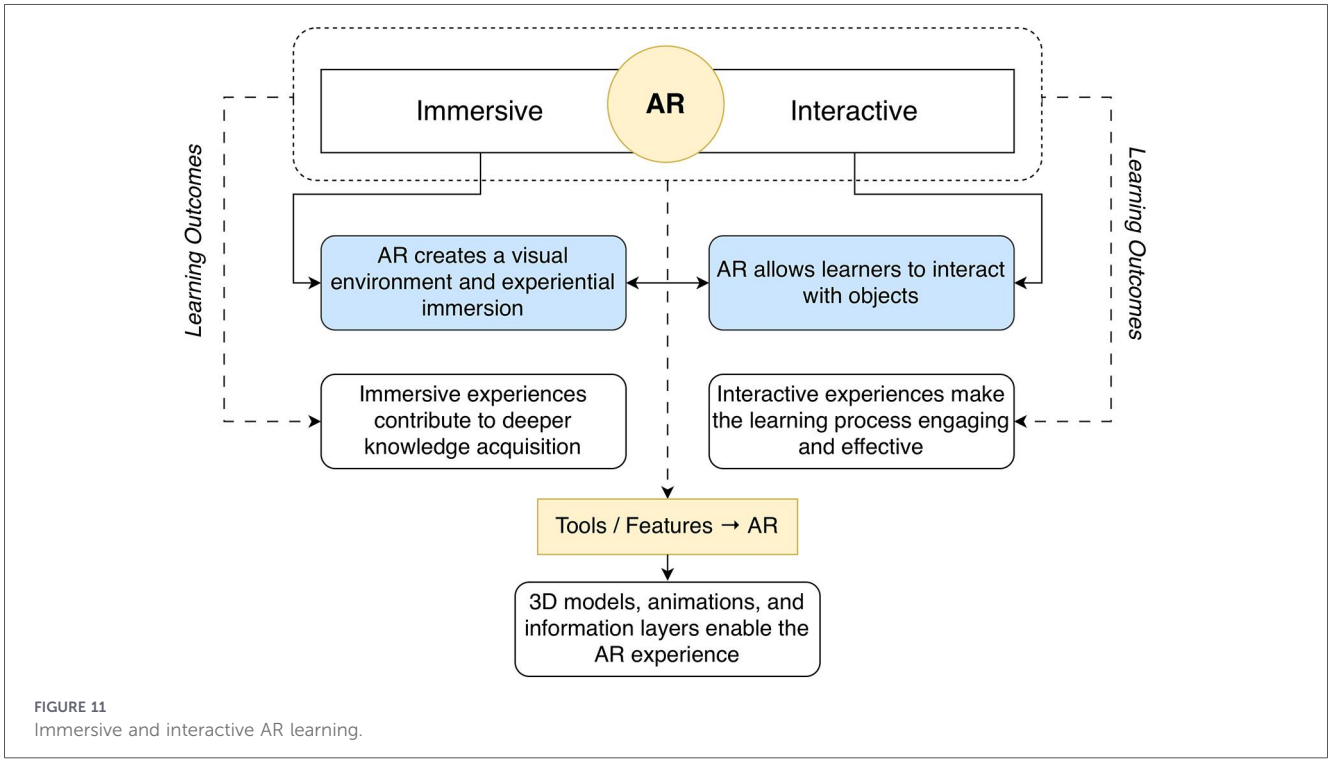

FIGURE 11
Immersive and interactive AR learning.

TABLE 5 Applications of AR in various fields.

Field/ framework	Description	Reference
Gamification	Boosts collaboration, motivation, and interactive engagement through educational games.	Sakr and Abdullah (2024)
Multimedia technologies	Enhances cultural experiences through virtual learning material with visual and auditory elements.	Prasetya et al. (2024)
ComTech (Communication Technologies)	Uses AR in diagnostic imaging to demonstrate educational and practical visualization.	Barta et al. (2024)
Online platforms	Uses AR layering to enhance marketing and educational interactivity online.	Bretos et al. (2023)
Social media and messaging	Uses AR in tourism to enhance social interaction and experience sharing.	Lastrucci et al. (2024)

construction of knowledge (Thangavel, 2025). Thus, the concepts of inclusivity and interactivity in AR technology complement each other, making the learning process as realistic, interesting and experience-oriented as possible. This approach allows you to visually explain complex theoretical concepts and develop students ' practical skills in a safe learning environment. The importance of digital technologies in the modern education system is growing from year to year, which clearly demonstrates their role in improving the quality of Education. Researchers have identified the main aspects of the impact of various technologies on the learning process. For example, AR technologies are viewed from several perspectives: Manurung et al. (2024) improving the real world through digital information; Shukla et al. (2024) emphasizing real-time interactive interaction; Nikolaidis (2022) emphasizing the integration of virtual and real elements. All research makes it possible to systematize the areas of application of AR within education (Table 5).

Modern digital learning technologies make it possible to improve the educational process in various areas. Technological resources such as VR, AR, gamification, multimedia, ComTech, online platforms, social networks and messaging tools define specific areas of application according to the theoretical definitions proposed by various authors.

3.4 Integration of AR technologies into the dual education system based on the SAMR model: the case of the E-dual.kz platform

In order to comprehensively assess the pedagogical level of implementation of Augmented Reality technologies in the dual education system, the SAMR model (Substitution, Augmentation, Modification, Redefinition) was used in this study. This model allows us to analyze the impact of digital technologies on the educational process not only as a technical tool, but also through the level of pedagogical transformation and transformation of educational activities. During the study E-dual.kz it was found that the use of AR technologies on the digital platform has made significant changes in the content and logic of the organization of dual learning.

At the Substitution and Augmentation levels of the SAMR model, AR technologies served as visualization and interactive presentation of educational materials, however, the learning structure has not undergone significant changes. And at the modification level, the platform reorganized the way students perform educational tasks, provided the ability to virtual simulate production processes, implement practical actions in a safe digital environment, and provide instant feedback. These changes have strengthened the relationship between theory and practice in the dual education system.

At the Redefinition level E-dual.kz the platform has created new learning formats that were previously impossible through AR technologies (Figure 12). Students had the opportunity to perform complex professional tasks in an immersive virtual environment close to real production conditions, analyze and correct mistakes and form an independent learning trajectory (Karabay et al., 2025).

Thus, the analysis carried out on the basis of the SAMR model showed that AR technologies and E-dual.kz it shows that the platform is an effective tool in the dual education system, not just as a digital tool, but as a pedagogical restructuring of the educational process. The obtained empirical results prove that this platform corresponds to the highest level of the SAMR model Redefinition and has a high pedagogical potential in increasing the academic success of students.

3.5 Research participants and group organisation

The study involved students from two educational institutions within Kazakhstan's technical and vocational education system: the College of Higher New Technologies named after Manap Utebayev and the College of South Kazakhstan University named after Mukhtar Auezov. Participants were selected on the basis of institutional accessibility and administrative approval (convenience sampling). All students were enrolled in the *Web Programming* course under one of two specialisations: 4S06130103-Software Developer and 4S06130105-Information Systems Technician.

The assignment of groups was not randomized, instead intact academic classes were used, which is a natural feature of quasi-experimental research designs. The **Experimental Group** (EG) used the AR modules of the E-dual.kz platform, while the **Control Group** (CG) followed the traditional dual education programme. The total sample comprised $N = 410$ students across three academic years (EG = 205, CG = 205), distributed by year as follows:

- **2023–2024 academic year:** EG - $N = 77$, CG - $N = 78$
- **2024–2025 academic year:** EG - $N = 78$, CG - $N = 77$
- **2025–2026 academic year:** EG - $N = 50$, CG - $N = 50$

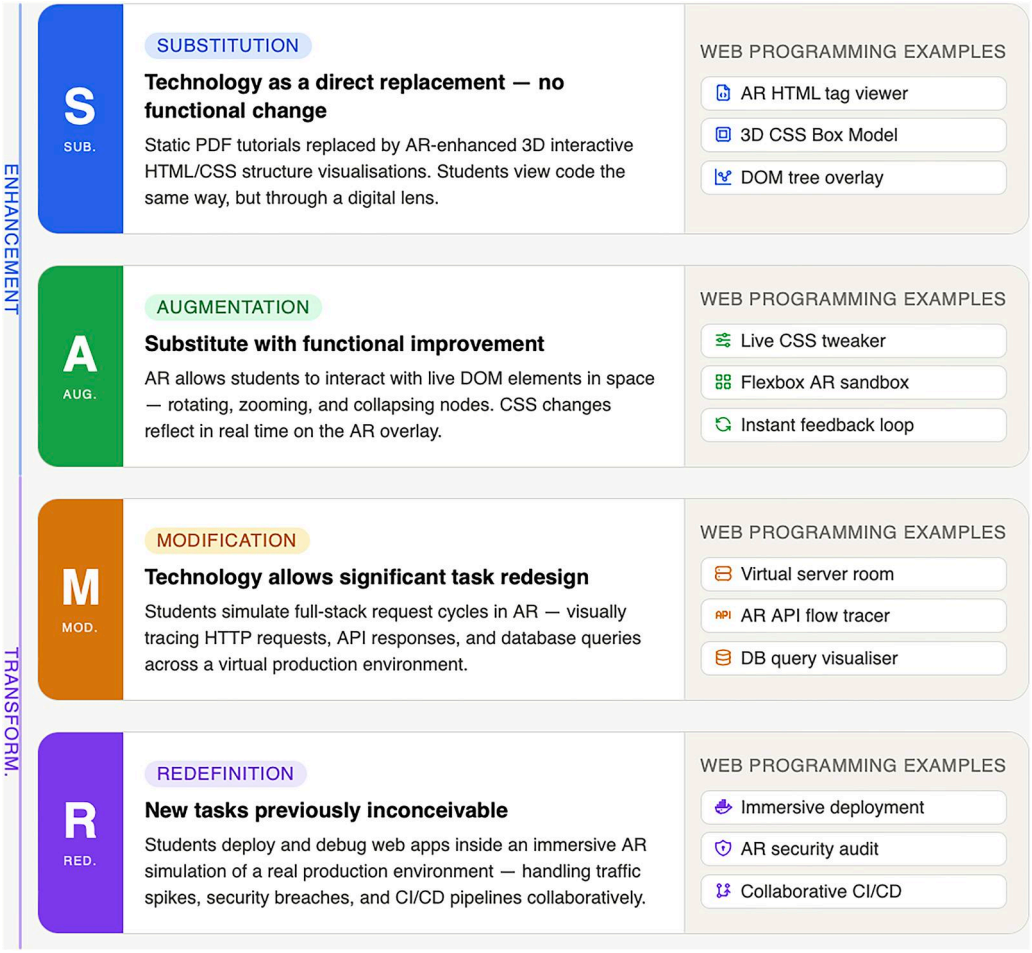

FIGURE 12
SAMR model-AR technology integration in web programming education.

To verify the initial equivalence of the groups, the results of the pre-test administered at the beginning of each academic year were compared. The obtained values confirmed that both groups demonstrated similar levels of prior knowledge at the start of the study.

Student achievement was assessed at two measurement points: the *pre-test* and the *post-test*. The assessment scale was divided into three levels: **Low** (0–49 points), **Medium** (50–74 points), and **High** (75–100 points). The test items were jointly developed by specialists from both educational institutions and verified for content validity.

4 Results

This section presents the quantitative outcomes of the quasi-experimental study conducted across three consecutive academic years (2023–2024, 2024–2025, and 2025–2026). The analysis compares the Experimental Group (EG), which integrated AR-based modules through the E-dual.kz platform, with the Control Group (CG), which followed the conventional dual education curriculum. For each academic year, the following indicators are reported: the distribution of students by proficiency level at pre-test (diagnostic experiment, DE) and post-test (formative experiment, FE); weighted group mean scores ($\bar{X}_1$ and $\bar{X}_2$); mean gain ($\Delta\bar{X}$); pooled standard deviation (S_{pool}); Cohen's d effect size; paired-samples t-statistic; and the rate of transition to the High proficiency level. Taken together, these measures allow for a systematic and comparable evaluation of learning outcomes across all three cohorts. Figure 13 presents the aggregated distribution of students by proficiency level across all three cohorts for both groups, each comprising 205 students. The data indicate that following the formative experiment, the EG achieved a more pronounced shift toward higher proficiency levels - with the Low-level share declining from 16.1% to 10.7% and the High-level share rising from 15.7% to 18.1% - compared to the more modest gains observed in the CG, where the Low-level proportion decreased from 23.4% to 18.5% and the High-level proportion increased marginally from 13.9% to 15.6%.

4.1 Academic year 2023–2024

Sample: $n_{\text{EG}} = 77$, $n_{\text{CG}} = 78$. EG sub-groups: SD-23-01, IS-23-01, SD-23-01T, SD-24-01. CG sub-groups: SD-23-02, IS-23-02, IS-23-01T, SD-24-02.

Group		Total number of students	Ascertaining experiment						Formative experiment					
Level			Low		Medium		High		Low		Medium		High	
			Number of students	%	Number of students	%	Number of students	%	Number of students	%	Number of students	%	Number of students	%
EG	SD-23-01	25	3	12,0	18	72,0	4	16,0	2	8,0	19	76,0	4	16,0
	IS-23-01	25	3	12,0	17	68,0	5	20,0	2	8,0	17	68,0	6	24,0
	SD-23-01 T	27	4	14,8	19	70,4	4	14,8	3	11,1	20	74,1	4	14,8
	SD-24-01	25	5	20,0	15	60,0	5	20,0	3	12,0	17	68,0	5	20,0
	IS-24-01	25	5	20,0	16	64,0	4	16,0	3	12,0	17	68,0	5	20,0
	IS-24-01 T	28	4	14,3	21	75,0	3	10,7	3	10,7	21	75,0	4	14,3
	SD-25-01	25	4	16,0	17	68,0	4	16,0	3	12,0	17	68,0	5	20,0
	IS-25-01	25	5	20,0	17	68,0	3	12,0	3	12,0	18	72,0	4	16,0
Average indicators by level (%)		205	33	16,1	140	68,2	32	15,7	22	10,7	146	71,1	37	18,1
CG	SD-23-02	25	6	24,0	15	60,0	4	16,0	5	20,0	15	60,0	5	20,0
	IS-23-02	25	4	16,0	18	72,0	3	12,0	3	12,0	18	72,0	4	16,0
	IS-23-01 T	28	8	28,6	15	53,6	5	17,9	6	21,4	17	60,7	5	17,9
	SD-24-02	25	5	20,0	18	72,0	2	8,0	3	12,0	20	80,0	2	8,0
	IS-24-02	25	6	24,0	15	60,0	4	16,0	5	20,0	16	64,0	4	16,0
	SD-24-01 T	27	7	25,9	17	63,0	3	11,1	5	18,5	18	66,7	4	14,8
	SD-25-02	25	8	32,0	12	48,0	5	20,0	6	24,0	14	56,0	5	20,0
	IS-25-02	25	6	24,0	17	68,0	2	8,0	5	20,0	17	68,0	3	12,0
Average indicators by level (%)		205	50	23,4	127	62,1	28	13,9	38	18,5	135	65,9	32	15,6

FIGURE 13
Distribution of students by proficiency level: ascertaining and formative experiment results (2023–2026).

4.1.1 Level distribution

Students were classified into three proficiency levels based on diagnostic test scores (Low/Medium/High).

Result: In the EG, the Low-level share decreased from 12.99% to 7.79%, and the High-level share increased from 16.88% to 20.78%. In the CG, the High-level share declined from 15.38% to 14.10%.

4.1.2 Weighted group means

The weighted mean was computed by assigning the level midpoint score to each student (Table 7):

$$\bar{X} = \frac{n_{\text{Low}} \times 40 + n_{\text{Med}} \times 62 + n_{\text{High}} \times 83}{n_{\text{total}}}$$

Result: The EG mean increased by 1.96 pts - 6.8× greater than the CG gain (0.29 pts).

4.1.3 Pooled standard deviation (S_{pool})

The pooled standard deviation is computed as the square root of the arithmetic mean of PRE and POST variances, and serves as the denominator for Cohen's *d*, as shown in Equations (1–3).

$$S_{\text{pool}} = \sqrt{\frac{S_1^2 + S_2^2}{2}} \quad (1)$$

$$S_{\text{pool}}^{\text{EG}} = \sqrt{\frac{136.84 + 122.33}{2}} = \sqrt{\frac{259.17}{2}} = \sqrt{129.59} = 11.38 \quad (2)$$

$$S_{\text{pool}}^{\text{CG}} = \sqrt{\frac{176.13 + 159.07}{2}} = \sqrt{\frac{335.20}{2}} = \sqrt{167.60} = 12.95 \quad (3)$$

Result: CG scores were more dispersed ($S_{\text{pool}} = 12.95$) than EG scores ($S_{\text{pool}} = 11.38$).

4.1.4 Cohen's *d* effect size

Cohen's *d* is the ratio of the mean gain to the pooled standard deviation (Table 8), as shown in Equation (4).

$$d = \frac{\Delta\bar{X}}{S_{\text{pool}}} \quad (4)$$

Benchmarks: $d < 0.20$—small; $0.20 \leq d < 0.50$—medium; $d \geq 0.50$—large, as shown in Equations (5–7).

$$d^{\text{EG}} = \frac{+1.96}{11.38} = 0.172 \text{ (small effect)} \quad (5)$$

$$d^{\text{CG}} = \frac{+0.29}{12.95} = 0.023 \text{ (small effect)} \quad (6)$$

$$\eta = d^{\text{EG}} - d^{\text{CG}} = 0.172 - 0.023 = 0.149 \text{EG advantage} : 7.5 \times \quad (7)$$

Result: $d^{\text{EG}} = 0.172$ is 7.5× greater than $d^{\text{CG}} = 0.023$. EG advantage $\eta = 0.149$.

4.1.5 Paired *t*-test ($r = 0.70$; $df = 76$; $t_{\text{crit}} \approx 1.98$)

The paired *t*-test (Table 9) assessed whether within-group improvement (PRE→POST) was statistically significant. The PRE–POST correlation was assumed $r = 0.70$ ($df = 76$, $\alpha = 0.05$, $t_{\text{crit}} \approx 1.98$).

TABLE 6 2023–2024: Proficiency level distribution.

Group	PRE low	PRE Med.	PRE high	POST low	POST Med.	POST high
EG	10 (12.99%)	54 (70.13%)	13 (16.88%)	6 (7.79%)	55 (71.43%)	16 (20.78%)
CG	18 (23.08%)	48 (61.54%)	12 (15.38%)	16 (20.51%)	51 (65.38%)	11 (14.10%)

TABLE 7 2023–2024: Weighted group means.

Group	$\bar{X}_1$ (PRE)	$\bar{X}_2$ (POST)	$\Delta\bar{X}$ (Gain)
EG	62.69	64.65	+1.96 pts
CG	60.15	60.45	+0.29 pts

TABLE 8 2023–2024: Cohen's d effect size.

Group	$\Delta\bar{X}$	S_{pool}	d	Level
EG	+1.96 pts	11.38	0.172	Small effect
CG	+0.29 pts	12.95	0.023	Small effect

TABLE 9 2023–2024: Paired t-test results.

Group	n	S_{pool}	SE_{diff}	t	Decision
EG	77	11.38	1.005	1.952	$p \geq 0.05$
CG	78	12.95	1.135	0.260	$p \geq 0.05$

The standard error of the difference is as shown in Equation (8).

$$SE_{\text{diff}} = \frac{S_{\text{pool}} \cdot \sqrt{2(1-r)}}{\sqrt{n}} \tag{8}$$

and the test statistic as shown in Equation (9)

$$t = \frac{\Delta\bar{X}}{SE_{\text{diff}}} \tag{9}$$

Experimental Group (EG, $n = 77$) as shown in Equation (10, 11).

$$SE^{\text{EG}} = \frac{11.38 \times \sqrt{2(1-0.70)}}{\sqrt{77}} = \frac{11.38 \times \sqrt{0.60}}{8.775} = \frac{11.38 \times 0.7746}{8.775} = \frac{8.815}{8.775} = 1.005 \tag{10}$$

$$t^{\text{EG}} = \frac{+1.96}{1.005} = 1.952 t^{\text{EG}} < t_{\text{crit}},\ p \geq 0.05 \tag{11}$$

Control Group (CG, $n = 78$) as shown in Equation (12, 13).

$$SE^{\text{CG}} = \frac{12.95 \times \sqrt{0.60}}{8.832} = \frac{12.95 \times 0.7746}{8.832} = \frac{10.031}{8.832} = 1.135 \tag{12}$$

$$t^{\text{CG}} = \frac{+0.29}{1.135} = 0.260 p \geq 0.05 \tag{13}$$

Result: $t^{\text{EG}} = 1.952 > t^{\text{CG}} = 0.260$. Although statistical significance was not reached ($t_{\text{crit}} \approx 1.98$), the EG t-value was 7.5× higher.

4.1.6 High-level advancement rate

Result: EG added 3 students to High level (+3.90 pp, +23.08%); CG lost 1 student (−1.28 pp, −8.33%).

4.2 Academic year 2024–2025

Sample: $n_{\text{EG}} = 78$, $n_{\text{CG}} = 77$.

4.2.1 Weighted group means

Experimental Group (EG) as shown in Equation (14–16).

$$\bar{X}_1^{\text{EG}} = \frac{14 \times 40 + 52 \times 62 + 12 \times 83}{78} = \frac{560 + 3224 + 996}{78} = \frac{4780}{78} = 61.28 \tag{14}$$

$$\bar{X}_2^{\text{EG}} = \frac{9 \times 40 + 55 \times 62 + 14 \times 83}{78} = \frac{360 + 3410 + 1162}{78} = \frac{4932}{78} = 63.47 \tag{15}$$

$$\Delta\bar{X}^{\text{EG}} = 63.47 - 61.28 = +2.19 \text{ pts} \tag{16}$$

Control Group (CG) as shown in Equation (17–19).

$$\bar{X}_1^{\text{CG}} = \frac{18 \times 40 + 50 \times 62 + 9 \times 83}{77} = \frac{720 + 3100 + 747}{77} = \frac{4567}{77} = 59.31 \tag{17}$$

$$\bar{X}_2^{\text{CG}} = \frac{13 \times 40 + 54 \times 62 + 10 \times 83}{77} = \frac{520 + 3348 + 830}{77} = \frac{4698}{77} = 61.01 \tag{18}$$

$$\Delta\bar{X}^{\text{CG}} = 61.01 - 59.31 = +1.70 \text{ pts} \tag{19}$$

4.2.2 Pooled standard deviation

Pooled standard deviation is as shown in Equation (20–21).

$$S_{\text{pool}}^{\text{EG}} = \sqrt{\frac{154.20 + 133.49}{2}} = \sqrt{143.85} = 11.99 \tag{20}$$

$$S_{\text{pool}}^{\text{CG}} = \sqrt{\frac{157.46 + 138.01}{2}} = \sqrt{147.74} = 12.15 \tag{21}$$

TABLE 10 2023–2024: high-level advancement.

Group	PRE high	POST high	Gain (pp)	Gain (%)	Advantage
EG	13 (16.88%)	16 (20.78%)	+3.90 pp	+23.08%	EG
CG	12 (15.38%)	11 (14.10%)	−1.28 pp	−8.33%	–

Result: Dispersions are close (EG: 11.99/CG: 12.15), yielding a reliable Cohen's *d* comparison.

4.2.3 Cohen's *d* effect size

Cohen's *d* effect size is as shown in Equation (23, 24).

$$d^{EG} = \frac{+2.19}{11.99} = 0.183 \tag{22}$$

$$d^{CG} = \frac{+1.70}{12.15} = 0.140 \tag{23}$$

$$\eta = 0.183 - 0.140 = 0.043 \text{EG advantage} : 1.3 \times \tag{24}$$

Result: $d^{EG} = 0.183 > d^{CG} = 0.140$. The gap narrowed, but EG superiority was maintained.

4.2.4 Paired *t*-test ($r = 0.70$; $df = 77$; $t_{crit} \approx 1.98$)

Experimental Group (EG, $n = 78$) as shown in Equation (25, 26).

$$SE^{EG} = \frac{11.99 \times \sqrt{0.60}}{\sqrt{78}} = \frac{11.99 \times 0.7746}{8.832} = \frac{9.287}{8.832} = 1.052 \tag{25}$$

$$t^{EG} = \frac{+2.19}{1.052} = 2.082 p \geq 0.05 \tag{26}$$

Control Group (CG, $n = 77$) as shown in Equation (27, 28).

$$SE^{CG} = \frac{12.15 \times \sqrt{0.60}}{\sqrt{77}} = \frac{12.15 \times 0.7746}{8.775} = \frac{9.411}{8.775} = 1.073 \tag{27}$$

$$t^{CG} = \frac{+1.70}{1.073} = 1.586 p \geq 0.05 \tag{28}$$

Result: $t^{EG} = 2.082 > t^{CG} = 1.586$ (31.3% higher). Statistical significance was not reached (Table 11).

4.2.5 High-level advancement rate

Result: EG added 2 students to High level (+2.56 pp, +16.67%); CG added 1 student (+1.30 pp, +11.11%). EG advancement was 1.97× greater than CG (Table 12).

4.3 Academic year 2025–2026

Sample: $n_{EG} = 50$, $n_{CG} = 50$.

TABLE 11 2024–2025: Paired *t*-test results.

Group	*n*	S_{pool}	SE_{diff}	*t*	Decision
EG	78	11.99	1.052	2.082	$p \geq 0.05$
CG	77	12.15	1.073	1.586	$p \geq 0.05$

4.3.1 Weighted group means

Experimental Group (EG) as shown in Equation (29–31).

$$\bar{X}_1^{EG} = \frac{9 \times 40 + 34 \times 62 + 7 \times 83}{50} = \frac{360 + 2108 + 581}{50} = \frac{3049}{50} = 60.98 \tag{29}$$

$$\bar{X}_2^{EG} = \frac{2 \times 40 + 43 \times 62 + 5 \times 83}{50} = \frac{80 + 2666 + 415}{50} = \frac{3161}{50} = 63.22 \tag{30}$$

$$\Delta \bar{X}^{EG} = 63.22 - 60.98 = +2.24 \text{ pts} \tag{31}$$

Control Group (CG) as shown in Equation (32–34).

$$\bar{X}_1^{CG} = \frac{14 \times 40 + 29 \times 62 + 7 \times 83}{50} = \frac{560 + 1798 + 581}{50} = \frac{2939}{50} = 58.78 \tag{32}$$

$$\bar{X}_2^{CG} = \frac{11 \times 40 + 31 \times 62 + 8 \times 83}{50} = \frac{440 + 1922 + 664}{50} = \frac{3026}{50} = 60.52 \tag{33}$$

$$\Delta \bar{X}^{CG} = 60.52 - 58.78 = +1.74 \text{ pts} \tag{34}$$

Result: EG recorded the highest gain across all three years (+2.24 pts), suggesting progressive refinement of the AR design.

4.3.2 Pooled standard deviation

Pooled standard deviation is as shown in Equation (35, 36).

$$S_{pool}^{EG} = \sqrt{\frac{147.82 + 136.16}{2}} = \sqrt{141.99} = 11.92 \tag{35}$$

$$S_{pool}^{CG} = \sqrt{\frac{186.89 + 174.85}{2}} = \sqrt{180.87} = 13.45 \tag{36}$$

Result: Higher CG dispersion ($S_{pool} = 13.45$ vs. 11.92) reflects the heterogeneity of baseline proficiency.

TABLE 12 2024–2025: High-level advancement.

Group	PRE high	POST high	Gain (pp)	Gain (%)	Advantage
EG	12 (15.38%)	14 (17.95%)	+2.56 pp	+16.67%	EG
CG	9 (11.69%)	10 (12.99%)	+1.30 pp	+11.11%	–

TABLE 13 2025–2026: Paired t-test results.

Group	n	S_{pool}	SE_{diff}	t	Decision
EG	50	11.92	1.305	1.717	$p \geq 0.05$
CG	50	13.45	1.473	1.181	$p \geq 0.05$

4.3.3 Cohen's d effect size

Cohen's d effect size is as shown in Equation (37–39).

$$d^{EG} = \frac{+2.24}{11.92} = 0.188 \quad (37)$$

$$d^{CG} = \frac{+1.74}{13.45} = 0.129 \quad (38)$$

$$\eta = 0.188 - 0.129 = 0.059 \text{EG advantage} : 1.5 \times \quad (39)$$

Result: $d^{EG} = 0.188$—the highest EG value across all three years, approaching the small-to-medium boundary.

4.3.4 Paired t-test ($r = 0.70$; $df = 49$; $t_{crit} \approx 2.01$)

Experimental Group (EG, $n = 50$**)** as shown in Equation (40, 41).

$$SE^{EG} = \frac{11.92 \times \sqrt{0.60}}{\sqrt{50}} = \frac{11.92 \times 0.7746}{7.071} = \frac{9.233}{7.071} = 1.305 \quad (40)$$

$$t^{EG} = \frac{+2.24}{1.305} = 1.717 p \geq 0.05 \quad (41)$$

Control Group (CG, $n = 50$**)** as shown in Equation (42, 43).

$$SE^{CG} = \frac{13.45 \times \sqrt{0.60}}{\sqrt{50}} = \frac{13.45 \times 0.7746}{7.071} = \frac{10.418}{7.071} = 1.473 \quad (42)$$

$$t^{CG} = \frac{+1.74}{1.473} = 1.181 p \geq 0.05 \quad (43)$$

Result: $t^{EG} = 1.717 > t^{CG} = 1.181$ (45.4% higher)—the largest relative gap among all three cohorts (Table 13).

4.3.5 High-level advancement rate

Result: EG added 2 students to High level (+4.00 pp, +28.57%); CG added 1 student (+2.00 pp, +14.29%). EG advancement was 2.0× greater than CG—the highest relative gain across all cohorts (Table 14).

4.4 Summary analysis: three academic years

Table 15 consolidates the six key statistical indicators -weighted group means, pooled standard deviation, Cohen's d effect size, paired t-statistic, and high-level advancement rate - across all three cohorts ($N = 410$), allowing a direct comparison of EG and CG performance year by year and in aggregate.

4.4.1 Cohen's d trend

Table 16 tracks the year-on-year dynamics of Cohen's d for both groups, alongside the between-group difference ($\eta = \Delta d$) and the EG/CG ratio, revealing a consistent upward trend in EG effect size across all three cohorts ($0.172 \rightarrow 0.183 \rightarrow 0.188$).

4.5 Summary findings

1. **The EG consistently outperformed the CG across all three years.** Cohen's d, the paired t-statistic, and the high-level advancement rate all pointed in the same direction. This rules out a chance trend.
2. **Effect sizes were in the small range** ($d < 0.20$)**, yet consistent.** The average $d^{EG} = 0.181$ vs. $d^{CG} = 0.097$ across three independent cohorts constitutes cumulative evidence of a real pedagogical difference.
3. **Statistical significance was not reached** ($p \geq 0.05$)**.** This is attributable to limited sample size. All year-on-year trends are unidirectional.
4. **2025–2026 was the EG's strongest year.** $d^{EG} = 0.188$ (highest across all cohorts), high-level advancement +4.00 pp (+28.57%), and a relative t-ratio of 45.4% above CG—indicating progressive maturation of the AR-enhanced design.
5. **The high-level advancement metric shows a clear trend.** The EG increased the number of High-level students in every year; the CG lost one student at this level in 2023–2024.

The Experimental Group (EG), trained via the AR-enhanced E-dual.kz platform, demonstrated superior pedagogical effectiveness over the Control Group (CG) following traditional dual instruction in all three academic years. Mean Cohen's d: EG $= 0.172 >$ CG $= 0.097$. High-level advancement: EG increased in every cohort; CG declined in 2023–2024. *The pedagogical effectiveness of AR-based dual learning is empirically supported across three independent cohorts ($N = 410$).*

TABLE 14 2025–2026: High-level advancement.

Group	PRE high	POST high	Gain (pp)	Gain (%)	Advantage
EG	7 (14.00%)	9 (18.00%)	+4.00 pp	+28.57%	EG
CG	7 (14.00%)	8 (16.00%)	+2.00 pp	+14.29%	–

TABLE 15 Cumulative results: all cohorts (2023–2026).

Group/year	n	$\bar{X}_1$	$\bar{X}_2$	$\Delta\bar{X}$	S_{pool}	d	t (p)	High
EG 2023–24	77	62.69	64.65	+1.96	11.38	0.172	1.952 ($p \geq 0.05$)	+3.90 pp
CG 2023–24	78	60.15	60.45	+0.29	12.95	0.023	0.260 ($p \geq 0.05$)	−1.28 pp
EG 2024–25	78	61.28	63.47	+2.19	11.99	0.183	2.082 ($p \geq 0.05$)	+2.56 pp
CG 2024–25	77	59.31	61.01	+1.70	12.15	0.140	1.586 ($p \geq 0.05$)	+1.30 pp
EG 2025–26	50	60.98	63.22	+2.24	11.92	0.188	1.717 ($p \geq 0.05$)	+4.00 pp
CG 2025–26	50	58.78	60.52	+1.74	13.45	0.129	1.181 ($p \geq 0.05$)	+2.00 pp
EG Mean	68.3	61.65	63.78	+2.13	11.76	0.181	–	–
CG Mean	68.3	59.41	60.66	+1.24	12.85	0.097	–	–

TABLE 16 Cohen's d dynamics (2023–2026).

Year	d^{EG}	d^{CG}	$\eta = \Delta d$	EG/CG ratio
2023–2024	0.172	0.023	0.149	7.5×
2024–2025	0.183	0.140	0.043	1.3×
2025–2026	0.188	0.129	0.059	1.5×
Average	0.181	0.097	0.084	1.9×

5 Discussion

5.1 Analysis and interpretation of the study results

The data collected over three academic years point in a clear direction. Students who studied through the AR-enhanced E-dual.kz platform consistently showed greater pre-to-post gains than their peers in the conventional dual-training programme. This held true not just in one cohort but in all three, which makes a coincidental explanation unlikely. Looking at the proficiency distribution, the share of Low-level students in the EG fell at the end of each year while the High-level share grew (Table 10). The CG showed a much more modest shift, and in 2023–2024 actually lost one student from the High-level category. These directional differences are consistent with findings from the international literature on AR in vocational education, where the technology has been shown to improve engagement and practical knowledge retention (Chen et al., 2025; Diao and Shih, 2019). The 2023–2024 cohort produced the sharpest contrast between groups. The EG mean gain was $\Delta\bar{X} = 1.96$ pts against only 0.29 pts for the CG, and the corresponding Cohen's d values were 0.172 and 0.023 respectively - a 6.8× difference in raw gain and a 7.5× difference in effect size. In 2024–2025 the picture changed somewhat: the CG improved noticeably ($\Delta\bar{X} = 1.70$ pts, $d = 0.140$), closing the gap with the EG ($\Delta\bar{X} = 2.19$ pts, $d = 0.183$). The gap narrowed, but the EG remained ahead. Then in 2025–2026 the EG recorded its best result across the entire study - a gain of 2.24 pts and $d = 0.188$, both higher than in either previous year. The CG also showed a solid gain (1.74 pts, $d = 0.129$), yet the EG advantage persisted.

None of the t-tests reached conventional statistical significance ($p \geq 0.05$). This is not surprising given the sample sizes involved $n = 77$–78 per group in the first two years and $n = 50$ per group in the third. With groups of this size, a small effect ($d < 0.20$) simply does not generate the statistical power needed to cross the $\alpha = 0.05$ threshold. What matters here is the consistency of direction: the EG t-statistic exceeded the CG value in every single cohort, and the average effect size over three years was $\bar{d}_{EG} = 0.181$ against $\bar{d}_{CG} = 0.097$. A pattern that repeats across three independent cohorts and three different statistical indicators is harder to dismiss than a single significant p-value from one study. It is also worth noting that all estimates are derived from proficiency-band midpoints rather than individual raw scores, which introduces some imprecision into the variance calculations. The high-level advancement figures reinforce this reading. The EG added students to the High category in every year: +3.90 pp in 2023–2024, +2.56 pp in 2024–2025, and +4.00 pp in 2025–2026. The CG, by contrast, lost ground in the first year (−1.28 pp) and recovered only modestly thereafter. The upward trajectory of the EG High-level rate, culminating in a +28.57% relative increase in 2025–2026, is perhaps the most practically meaningful finding of the study. Several implications follow. Access to AR-capable devices remains a real constraint (Table 6), and students with limited hardware access inevitably receive a diluted version of the intervention. Addressing this is a precondition for realising the full potential of the platform. Beyond infrastructure, AR modules need to be embedded in the assessed curriculum rather than treated as optional enrichment - otherwise student engagement with the technology will be uneven. Finally, the narrowing EG–CG gap in 2024–2025 is worth monitoring. It

may reflect genuine improvements in the conventional curriculum, which would raise the bar that any AR-based intervention must clear. If that is the case, the rebound in EG advantage in 2025–2026 suggests the platform is capable of responding to that challenge, but continuous updating of the AR content will be necessary to sustain it.

5.2 Cross-disciplinary applications of augmented reality in dual education

In the field of information technology, AR helps students to have a deeper understanding of IT infrastructure. Through the use of network modeling and virtual servers, future specialists will be able to visually study complex information systems in conditions very similar to real practice. This approach contributes to the development of logical thinking and system analysis skills, as well as increasing the effectiveness of practical training in dual education.

In technical and engineering disciplines, AR allows the visualization of industrial equipment in 3D and modeling of assembly instructions. In this way, students can gain work experience in a safe and secure environment without material costs, develop engineering thinking, and understand technical processes quickly and easily. In addition, they can master the operation of technological chains and mechanisms without access to real production facilities.

In the field of Agricultural Sciences, AR is widely used in the study of soil and plant structures, as well as in modeling the operation of agricultural machinery. Such virtual modeling allows you to safely analyze production scenarios, increase the effectiveness of training and improve practical skills. Students develop decision-making abilities in environments similar to real situations (Mohamad et al., 2024).

In the field of Medicine and pharmacy, AR technologies are widely used for the study of surgical modeling, anatomical research and pharmaceutical procedures. Such a virtual environment allows students to gain experience without putting patients at risk. Through this, they increase their professional competence and achieve the development of reliability, accuracy and responsibility in medical education (Hermansyah et al., 2025).

In the field of pedagogy and psychology, AR technologies make the learning process interactive and adaptive through electronic textbooks and virtual lessons. This will increase the competence of future teachers in digital pedagogy, as well as strengthen students ' contact with the subject. At the same time, immersive formats for psychological training and practical training significantly increase the level of student attendance (Beams and Crofton-Sleigh, 2024).

In the field of service, tourism and hospitality, AR technologies allow students to gain practical experience by organizing virtual tours, simulating customer service, and interactive maps. This approach contributes to the development of students ' communication skills, client-centered behavior, and organizational skills (Rauschnabel et al., 2022).

In Architecture, Design and construction, AR technologies allow for clear spatial visualization of projects. Three-dimensional models and virtual construction processes develop students spatial thinking and train them to work effectively on collaborative projects. This method improves practical design skills and creates conditions for the implementation of project ideas in real space.

In the arts and humanities, AR galleries and virtual museums offer interactive ways to explore cultural and artistic works. Students will be able to get to know the cultural heritage from a new angle, develop creative thinking and aesthetic perception. AR-based exhibitions and interactive displays make the learning process more attractive and informative, which increases students interest in the subject (Kapp et al., 2022).

The Figure 14 illustrates the use of augmented reality (AR) in the dual education system covers different areas. AR technologies allow students to acquire practical skills, visualize learning processes and interact interactively in different specialties. In

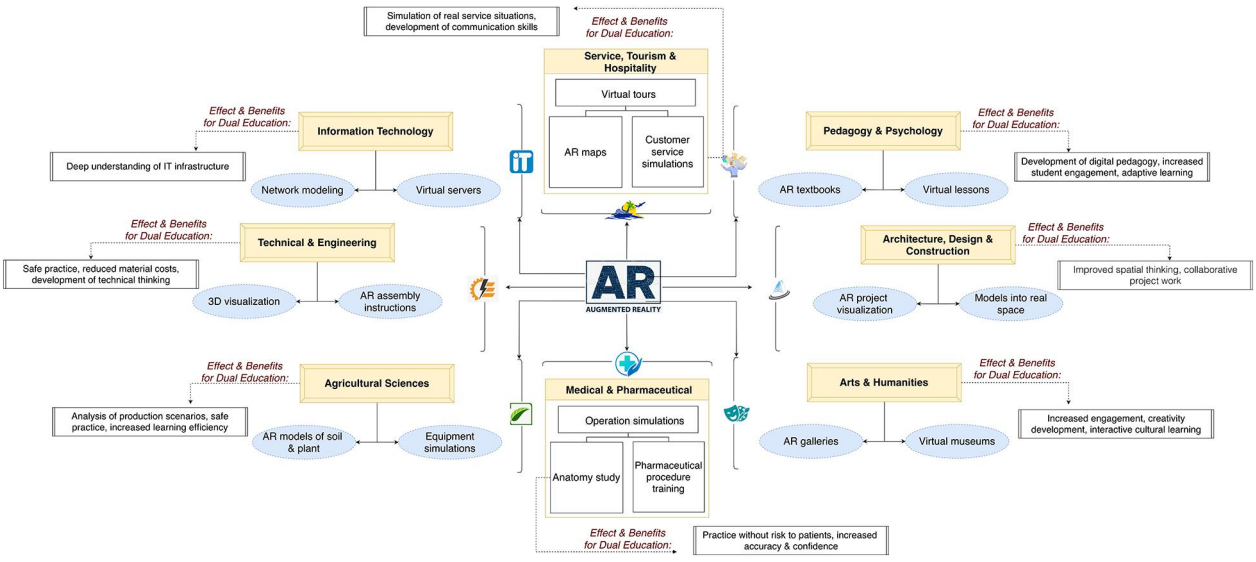

FIGURE 14
Roles of AR in enhancing learning and practice in dual education.

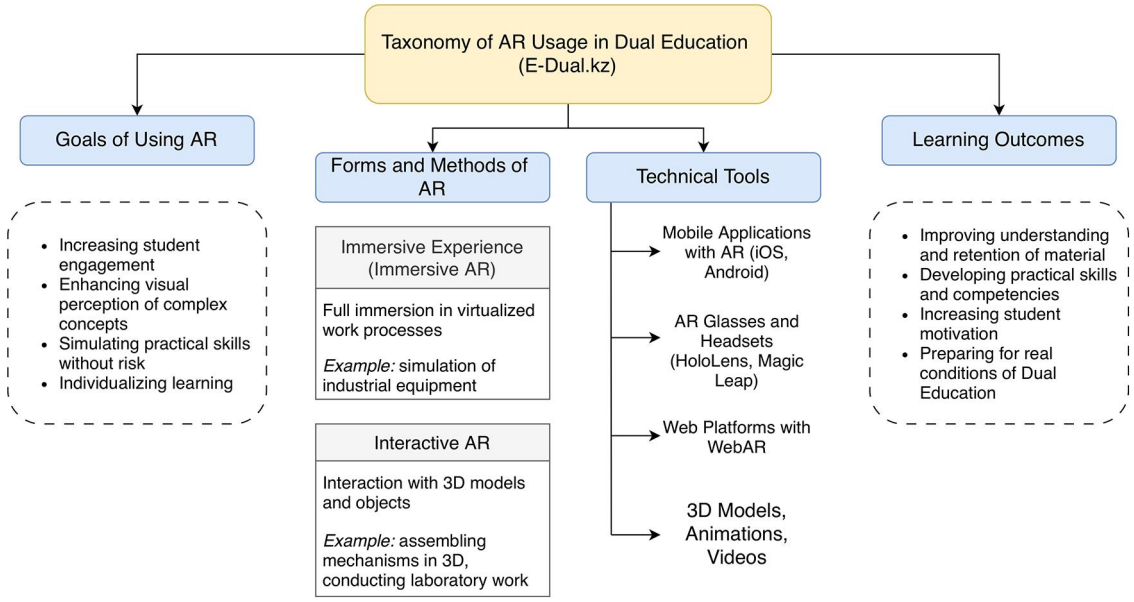

FIGURE 15
Taxonomy of AR usage in E-dual.

this way, the learning process will have an attractive, adaptive and experience-oriented character.

In general, augmented reality (AR) technology is being comprehensively implemented in all generations of the dual education system. This technology not only provides students with a safe, interactive and practice-oriented learning environment, but also allows them to reach a new level of development of their professional competencies (Koumpouros, 2024). In other words, AR is a tool that allows you to connect theoretical knowledge with life and increase the student's readiness for work by modeling real production situations. Such digital solutions turn dual education into an innovative mechanism capable of training modern and flexible specialists adapted to the requirements of the labor market.

Based on the analysis of current trends in digitalization in education, Zhukabayeva et al. (2025) propose to consider higher education institutions as dynamic ecosystems where institutional, technological, pedagogical and cultural-social levels closely interact. This approach allows not only to effectively manage the processes of digitalization, but also to integrate innovative solutions such as augmented reality technologies into the educational process, creating conditions for active and safe learning of practical skills. In particular, AR technologies help students to immediately link theoretical knowledge with practice, modeling real-world production situations and forming professional competencies, which is especially important for the dual education system. For example, students of construction specialties can see the structure of a building and understand the functions of its elements, and students of medical faculties can develop practical skills by studying the human body in a virtual environment, which increases their readiness for professional activity.

E-Dual.kz the application of AR technology on the platform is organized on the basis of a special taxonomy. This taxonomy is systematized according to educational goals, teaching methods, tools used, learning processes, pedagogical approaches, and expected learning outcomes. Such a structure allows teachers to determine strategies for the targeted and effective use of AR technologies. That is, the teacher can predict in advance which AR tool to use to develop a particular competence, what method to combine it with, and the expected result.

In addition, this taxonomy makes it possible to assess the impact of AR technology on the activities of students, the development of communicative and professional skills. With the help of AR, students ' interest in the subject increases, practical thinking, independent search skills and problem-solving abilities are formed. As a result, dual learning becomes not only an integration of theory and practice, but also a powerful environment for the development of digital competence. The Figure 15 below illustrates the taxonomy of AR technology application within the dual education system.

Taxonomy provides a clear direction for teachers to design AR-based learning practices according to specific competencies. It also allows you to assess the impact of AR on the development of student participation activity, skills, and overall learning outcomes.

6 Conclusions

The results of the study showed that the introduction of Augmented Reality (AR) technologies into the dual education system makes it possible to modernize its material, digitize the educational process and strengthen the relationship between theoretical knowledge and practical skills. AR elements, in addition to increasing the cognitive activity of students, create conditions for a visual explanation of complex production and technical processes, the formation of practical skills in a safe environment.

Analysis of international experience, literature and experimental data has proved that AR technologies have a positive impact on the motivation, academic achievement, and development of professional competencies of students. The results of the experiment showed that AR-based learning improves the level of students' perception of information, increases reliability in performing practical tasks, and the ability to act in an interactive environment.

E-dual.kz the development of a digital educational environment will form a new model for organizing dual training and strengthen the effectiveness of communication between an educational institution—an enterprise—a student. AR modules on the platform simulate production situations in a virtual format, allowing students to hone their professional skills.

At the same time, a number of restrictions have been identified in the large-scale use of AR technologies: insufficient material and technical base and infrastructure, low digital competencies of teachers, incomplete compatibility of AR learning material with curricula and lack of mechanisms for assessing long-term effectiveness. The solution to these problems is achieved through systematic support, training of personnel, improvement of infrastructure and adaptation of pedagogical models.

In general, AR technologies are a powerful tool for the modernization of dual education. It transfers the educational process to an interactive, practice-oriented and adapted to the individual educational trajectory. In the future, similar work is planned, and it is planned to improve the quality of dual training through the integration of AR, VR and artificial intelligence technologies, to train competitive specialists ready for the labor market.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/Supplementary Material.

Ethics statement

The research experiment involving human participants was reviewed and approved by the Ethics Committee of the College of higher new technologies named after Manap Utebayev (Protocol No. 5, March 10, 2025) and by the Ethics Committee of College of South Kazakhstan University named after M. Auezov (Protocol No. 7, March 10, 2025). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

AK: Software, Methodology, Writing – original draft, Investigation, Visualization, Resources, Validation. DB: Methodology, Supervision, Investigation, Funding acquisition, Software, Project administration, Writing – original draft, Validation. TZ: Investigation, Visualization, Data curation, Validation, Conceptualization, Formal analysis, Writing – review & editing. HB: Formal analysis, Writing – review & editing, Data curation, Methodology.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

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