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Comparative Analysis of VR/AR Platforms in Secondary Education: Integration Challenges and Pedagogical Potential

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Abstract:- The present study aims to conduct a comparative evaluation of six educational VR/AR platforms (Virbela, ClassVR, zSpace, Merge EDU, Assemblr EDU, and Quiver) on a five-point scale with regard to interactivity, educational value, applicability in economics education, ease of use, and accessibility. Methodologically, a theoretical-comparative approach is applied, integrating a systematic literature review, qualitative content analysis, and multi-criteria evaluation with the calculation of average scores. The results show that among the VR platforms, ClassVR and zSpace demonstrate the highest values for interactivity and educational value (both 5), with zSpace also having the highest applicability in economics (5), but lower accessibility (2) and more complex use (3); Virbela stands out for its highest accessibility (5) but has moderate applicability in economics (3). Among the AR platforms, Assemblr EDU demonstrates the highest applicability in economics education (4) and maximum ease of use (5), Quiver is most accessible (5) and easy to use (5) but with low economic applicability (2), while Merge EDU combines high interactivity and educational value (4), with moderate accessibility (3). The composite indices rank ClassVR (4.2) as the strongest platform, followed by zSpace and Virbela (each 4.0), Assemblr EDU and Quiver (each 3.8), and Merge EDU (3.6). The conclusions support a differentiated implementation model: VR for highly immersive and simulation-intensive scenarios where robust infrastructure and teacher training are available, and AR for scalable, resource-efficient, and easily integrated solutions.

Keywords*: digital education, applications, Virtual Reality (VR), Augmented Reality (AR).*

1. Introduction

The digital transformation of education is accelerating the integration of immersive technologies such as Virtual Reality (VR) and Augmented Reality (AR) into secondary education. While these technologies are increasingly presented as innovative tools for boosting student engagement and reinforcing the STEM concept (European Commission, STEM education, 2026) - learning through experience - comparative analyses of VR/AR platforms remain limited.

The aim of the present study is to conduct a comparative evaluation of six VR/AR educational platforms using a five-point scale, assessing interactivity, educational value, applicability to economics education, ease of use, and accessibility. The results, based on average scores, indicate that VR platforms demonstrate a stronger immersive potential and greater depth of experience, whereas AR platforms offer greater flexibility, lower barriers to implementation, and broader applicability within the classroom environment (De Moraes Rossetto et al., 2023). The findings support the view that VR/AR should not be seen as standalone innovations, but rather as components of a broader ecosystem for digital transformation, aligned with curriculum goals and the long-term sustainability of education.

Research emphasizes the importance of evaluating these technologies within a comparative analytical model that takes into account their alignment with educational objectives, technological infrastructure, and teacher readiness (Shankar et. al, 2023). Key factors such as user engagement, content adaptability, and accessibility are essential for determining the pedagogical effectiveness of VR and AR platforms (De Moraes Rossetto et al., 2023; Thangavel et al., 2025). Studies show that immersive VR simulations can support cognitive development by allowing students to explore abstract concepts in a controlled virtual space, while AR's ability to contextualize educational materials in real-world settings aids knowledge reinforcement through practical application (Poupard et al., 2024; Crogman et al., 2025;).

Despite these advantages, the literature also identifies significant challenges in the digital integration of VR/AR technologies into existing secondary school curricula. Issues such as hardware compatibility, limited user accessibility, and lack of content standardization hinder their seamless implementation (Ghanbaripour et al., 2024; Danmali et al., 2025;). Additionally, teacher preparation and institutional support are critical for overcoming these barriers, as educational professionals require relevant training and resources to implement these platforms effectively. The interaction between technological infrastructure and pedagogical goals remains a central aspect when assessing the applicability of VR/AR in schools (Kazakova, 2024).

The comparative framework proposed in recent studies serves as a decision-making tool for educators, highlighting the strengths and weaknesses of each platform (Thangavel et al., 2025). The fully immersive nature of VR is suitable for scenarios requiring intense focus and the simulation of complex environments, whereas the layering capabilities of AR are more appropriate for enhancing real-world interaction and enriching existing teaching methods (Jantanukul, 2024; Singh & Awasthi, 2024). This understanding facilitates the selection of VR or AR solutions tailored to the specific context of an educational institution, optimizing both learning outcomes and digital integration.

The introduction of these technologies requires careful consideration of curriculum goals, available resources, and teacher readiness to ensure effective implementation. Furthermore, continuous assessment and feedback are essential for adapting and refining the use of VR/AR in the classroom. Ultimately, the strategic deployment of digital technologies can transform secondary education by driving engagement, interactivity, and personalized learning experiences (Wang & Huang, 2025).

An important aspect of ensuring effective implementation is also accounting for infrastructure, costs, and training of educational professionals. Educators need to assess the compatibility of these tools with existing curricula and the specific needs of their students (Kotsis, 2025). Ultimately, a combined approach that leverages the unique advantages of both VR and AR can offer the most comprehensive educational experience in secondary education.

Ogbuehi & Fraser’s opinion highlights the role of technology in creating a better learning environment, fostering a more positive attitude towards mathematics, and achieving better conceptual development among secondary school students (Ogbuehi & Fraser, 2007). The advent of mobile technologies, according to Briz-Ponce et al., also facilitates a more interactive and personalized experience, which is essential to meet the diverse needs of today’s learners (Briz-Ponce et al., 2017). This shift represents a significant trend, with educational institutions increasingly adopting innovative technologies to promote engagement and improve educational outcomes.

2. Objectives

The aim of this study is to conduct a comparative assessment of six VR/AR educational platforms by analyzing them on a five-point scale in terms of pedagogical alignment, technological functionality, accessibility, and institutional applicability. The results, based on the average scores obtained, show that VR platforms demonstrate a stronger immersive potential and greater depth of experience, especially in STEM disciplines and simulation-based contexts, while AR platforms offer greater flexibility, lower barriers to implementation, and higher applicability in educational settings (De Moraes Rossetto et al., 2023). The conclusions support the viewpoint that VR/AR should not be considered as standalone innovations, but as components of a broader ecosystem for digital transformation, aligned with curriculum goals and the long-term sustainability of education.

3. Methods

The study applies a theoretical-comparative research method, integrating qualitative content analysis and multicriteria evaluation of selected VR/AR educational platforms. The methodological framework consists of three stages. First, a systematic review of literature sources focused on the integration of VR/AR technologies in secondary education was conducted. Second, an analysis was performed using a comparative evaluation on a five-point scale of six educational platforms (Virbela, ClassVR, zSpace, Merge EDU, Assemblr EDU, and Quiver). The selection criteria include relevance to the educational context, institutional acceptance, and functional diversity. Third, based on the obtained results from the examined VR/AR technologies, average ratings were derived using five criteria: (1) interactivity, (2) educational value, (3) applicability in economic education, (4) ease of use, and (5) accessibility. Through comparative analysis, a summary was made that reveals differences in the performance of VR/AR technologies. The methodological approach ensures analytical transparency and reproducibility, making it suitable for empirical extension in future research contexts.

Theoretical frameworks

Based on these practical implementations and challenges, the following section presents the theoretical foundations that guide research and innovation in virtual reality (VR) and augmented reality (AR). Their introduction into secondary education should be considered through an interdisciplinary theoretical lens that connects learning theory, pedagogy, and models of technological innovation. Digital technologies are not inherently neutral in their pedagogical application; their educational effectiveness depends on their alignment with established cognitive and instructional principles. Therefore, the present study builds its analysis on four complementary conceptual theories: 1) constructivist and experiential learning theory, 2) cognitive theory of multimedia learning, and frameworks for the integration of digital competence.

1. Constructivism and Experiential Learning

Constructivism states that knowledge is actively built through interactions with the surrounding environment rather than passively received. Digital environments created through VR/AR platforms provide interactive conditions that support problem-based learning and authentic problem-solving. In secondary education, such learning allows students to explore abstract concepts, such as molecular structures, historical reconstructions, or geographical phenomena, through firsthand experience. Experiential learning theory further reinforces this idea by emphasizing the cyclical process of concrete experience, reflective observation, abstract conceptualization, and active experimentation. VR simulations and AR-enhanced visualizations facilitate this cycle by allowing learners to manipulate variables, observe results, and test hypotheses in a controlled yet realistic environment. The digital element enhances spatial thinking and leads to deeper conceptual retention, especially in STEM disciplines (Pellas et al., 2020; Animashaun et al., 2024;).

2. Cognitive Load and the Theory of Multimedia Learning

From a cognitive perspective, the effectiveness of immersive technologies should be assessed in light of cognitive load theory and multimedia learning theory. Although VR/AR can increase engagement and provide multimodal representations, they can also raise excessive cognitive loads if poorly designed. Therefore, it is necessary to balance sensory richness with instructional clarity, ensuring that interactivity supports rather than distracts from the core learning objectives. The principles of multimedia learning, such as coherence, signaling, spatial contiguity, and modality, are particularly relevant when evaluating platform designs. Platforms that introduce guided interactions, structured storytelling, and step-by-step tasks are more likely to result in meaningful learning outcomes than those that rely solely on visual interactivity. Consequently, pedagogical alignment becomes a key evaluative criterion in the comparative analysis of digital platforms (Xie et al., 2023; Petruse et al., 2024; Surbakti et al., 2024).

3. Digital Competence and Models for Pedagogical Integration

The educational impact of VR and AR is closely linked to teachers' digital competencies and institutional strategies for integration. The European Framework for the Digital Competence of Educators (DigCompEdu) conceptualizes educators' digital competence in areas such as professional engagement, digital resources, teaching and learning, assessment, and learner empowerment (European Commission, DigCompEdu). These technologies require advanced skills for pedagogical organization, including classroom management in hybrid environments and critical evaluation of digital content (Kazakova, 2025). Moreover, integration models such as SAMR (Substitution, Augmentation, Modification, Redefinition) and TPACK (Technological Pedagogical Content Knowledge) provide analytical tools for assessing the transformational potential of VR/AR. At lower levels of integration, digital tools merely replace traditional visual aids; at higher levels, they redefine learning tasks by enabling experiences that are inaccessible in a conventional classroom. The TPACK framework emphasizes the need to balance technological knowledge with pedagogical and subject-specific expertise to achieve meaningful educational innovation (Belda-Medina & Calvo-Ferrer, 2022; Jordan et al., 2025).

From the frameworks outlined above, the following conclusions could be drawn:

- innovative technologies such as vr/ar go beyond the role of simple tools in the classroom, being integrated into a broader ecosystem of digital transformation that requires coordinated institutional management and sustainable funding;
- the effective adoption of interactive learning depends on comprehensive teacher training systems and alignment with educational standards to ensure pedagogical consistency;
- from the perspective of innovation systems, vr/ar act as catalysts for pedagogical change only when supported by strategic frameworks at both the school and institutional levels.
- the success of innovations depends on their incorporation into systemic institutional support structures, highlighting the importance of governance and policy integration;
- VR/AR should be considered pedagogically mediated innovations, whose effect depends on cognitive principles, experiential learning design, and the development of digital competencies among learners and pedagogical specialists;
- a systemic approach to interactive learning ensures that the implementation of technologies is not isolated, but part of a coordinated effort involving multiple stakeholders and resources;
- the integrated theoretical framework emphasizes that the effectiveness of digital technologies depends on their alignment with broader educational strategies and institutional capacities;
- the transformative potential of digital learning is realized through the interaction between technology, pedagogy, and systemic support, rather than solely through the implementation of technologies.

Analysis of VR/AR applications

Studies conducted during 2024–2025 reveal that VR/AR educational platforms are rapidly evolving with the integration of artificial intelligence (AI), enhanced accessibility, and specialized applications in medicine, vocational, and general education, although implementation challenges related to costs, infrastructure, and teacher training persist (Animashaun et al., 2024; Zou et al., 2025).

The latest systematic reviews have identified significant advances in the integration of AR/VR with AI, showing a remarkable annual growth of 60.58% in research publications (Lampropoulos, 2025). The convergence of these technologies demonstrates promising results in improving engagement, retention, and understanding among learners at all educational levels (Tihomirova & Atanasova, 2021).

VR/AR applications are also expanding into other specialized fields:

- The integration of game elements with pedagogical approaches creates more engaging educational experiences (Chatzea et al., 2025).
- Vocational training: AR enhances engagement and learning effectiveness in vocational education, although implementation continues to be hampered by infrastructure limitations (Indarta et al., 2025);
- Special education: VR demonstrates effectiveness in improving the physical, social, and cognitive abilities of students with disabilities through active-based learning (Chalkiadakis et al., 2024);
- Gamification and serious games: AR-based serious games are gaining popularity, with research showing positive impacts on student learning across behavioral, cognitive, emotional, motivational, mental, and overall performance dimensions. The integration of game elements with pedagogical approaches creates more engaging educational experiences (Chatzea et al., 2025).

The conclusion from the presented analysis shows that VR/AR technologies in education are developing dynamically and offer significant advantages in various fields, such as medical training, vocational preparation, and specialized education. Despite existing challenges related to infrastructure, costs, and teacher training, the integration of artificial intelligence and gamification contribute to increased engagement and effectiveness of the learning process.

The next step in the research is to specifically examine VR/AR applications used in secondary education by developing a comparative matrix, evaluated on a 5-point scale (from 1 – low to 5 – high value) according to the following key criteria: 1) level of interactivity; 2) educational value; 3) applicability in economic education; 4) ease of use; and 5) accessibility.

1. Interactivity: assesses the degree of learner engagement through interaction with the virtual environment—the presence of 3D objects, simulations, avatars, role-playing opportunities, or personalized scenarios.

2. Educational value: this criterion measures how well the content aligns with learning objectives, pedagogical principles, and curricula - the presence of structured learning materials, knowledge checks, teaching tools, and conformity with educational levels.

3. Applicability in economic education: evaluates how much the platform offers content or opportunities applicable to economic disciplines - such as market simulations, business environments, resource management, entrepreneurship, financial decision-making, etc.

4. Ease of use: analyzes how intuitive and accessible the interface is for both students and teachers - including the need for technical skills, support, and navigation within the system.

5. Accessibility: assesses how easily the platform can be introduced in Bulgarian or european educational contexts - with regard to pricing models, the need for specialized equipment, language versions, compatibility with various devices, and support.

Analysis of VR applications

Virtual reality (VR) platforms offer a variety of opportunities for educational interactivity and immersive experiences, which contribute to a deeper understanding of the study material (Analyti et al., 2024). The study compares three leading VR platforms: Virbela, ClassVR, and zSpace, and evaluates them according to five key criteria: interactivity, educational value, applicability in economics education, ease of use, and accessibility (Fig. 1).

1. Virbela: a platform designed for training, collaboration, and events in a fully virtual environment. It is widely used by universities and corporations to organize lectures, seminars, and business simulations. In the educational context, it is used to develop presentation, communication, and management skills through avatars and virtual spaces.

Tools: virtual auditoriums, offices, and common areas; opportunities for role-playing and interaction among participants; integration with training materials and presentations.

Results: improved communication and collaboration skills; increased motivation among pupils and students through a gamified environment; realistic experience during economic simulations (e.g., negotiations, trade).

Advantages:

- high level of interactivity and social presence;
- suitable for economic simulations and role-based training;
- it does not require specialized VR headsets.

Disadvantages:

- not specifically focused on educational content;
- more complex interface for younger students;
- requires a stable Internet connection and a computer with good specifications.

2. **ClassVR:** a platform specifically designed for schools and educational institutions. It offers ready-made VR lessons, resources, and tutorials on various subjects, including economics and entrepreneurship. The main goal was to create visually and emotionally impactful learning experiences for middle and high school students.

Tools: educational VR headsets with an easy-to-use interface; teacher's platform for content management and progress tracking; hundreds of premade lessons, scenarios, and case studies.

Results:

- increased concentration and engagement among students;
- better understanding of abstract economic concepts;
- improved student performance in STEM and economic disciplines.

Advantages:

- focused on the school educational environment;
- easy for teachers without technical experience to use;
- content is organized by age group and subject.

Disadvantages:

- does not allow for creation of custom simulations;
- equipment (VR headsets) is relatively expensive;
- more limited personalization compared to other platforms.

3. **zSpace:** combines elements of Augmented Reality (AR) and Virtual Reality (VR) using a special display and glasses. It is designed for hands-on learning in various fields, including economics, healthcare, engineering, and natural sciences. In economic disciplines, zSpace allows students to interact with virtual models of businesses, markets, and resources.

Tools: special monitor with motion tracking; stylus for manipulating 3D objects; educational software with modules for simulations (including economics and entrepreneurship).

Results:

- enhanced practical orientation of training;
- improved spatial thinking and problem-solving skills;
- increased interest in entrepreneurship and financial simulations.

Advantages:

- high technological level and advanced visualization;
- suitable for practical training and laboratory work;
- applicable across a wide range of disciplines.

Disadvantages:

- requires specific equipment, which is expensive;
- more difficult to integrate into a regular classroom;
- training of teaching specialists is mandatory.

Figure 1 visualizes the results of the analysis according to the five key criteria of the VR educational platforms reviewed. They highlight the differences and strengths of each platform in the context of their applicability in secondary education. This comparative approach provides a structured basis for choosing an appropriate VR platform according to specific pedagogical and technological requirements.

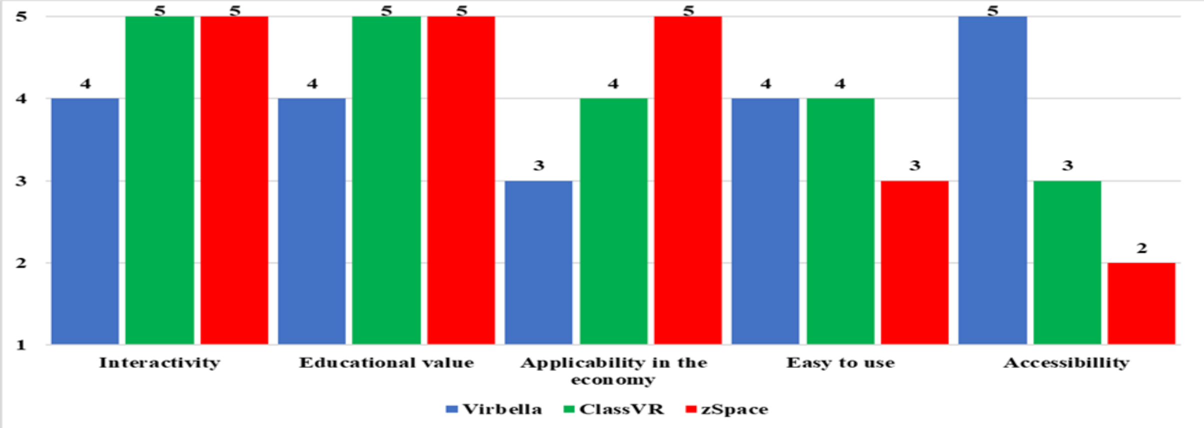

Fig. 1 Comparative analysis of VR platforms in education
Source: *Author's research*

The interpretation of the data shown in Fig. 1 reveals that ClassVR and zSpace demonstrated the highest levels for the criteria of "Interactivity" and "Educational value" (5 points each), while Virbela attained slightly lower scores (4 points in both categories). This suggests that digital hardware environments (ClassVR and zSpace) can offer richer opportunities for experiential learning than virtual collaborative platforms, such as Virbela. The strong performance of ClassVR and zSpace in these dimensions aligns with constructivist and experiential learning theories, in which immersive simulations enhance conceptual understanding and learner engagement.

Regarding "Applicability in economic education" zSpace achieved the highest score (5), followed by ClassVR (4) and Virbela (3). This distribution indicates that zSpace offers greater potential for modeling complex economic processes, simulations, and interactive scenarios. The lower score for Virbela may reflect its primary focus on virtual collaboration and meetings, rather than subject-specific simulations.

In terms of the "Easy of use" criterion, Virbela and ClassVR both received an equal score (4), in contrast to zSpace (3). This suggests that while zSpace provides advanced immersive features, its technological complexity may create usability barriers for teachers and students. The results underscore a well-known trade-off between technological complexity and operational simplicity in digital learning environments.

"Accessibility" revealed the most significant difference among the platforms. Virbela received the highest score (5), likely because of its compatibility with standard devices and lower infrastructure requirements. ClassVR received a moderate score (3), while zSpace had the lowest accessibility rating (2), reflecting its dependence on specialized hardware and higher implementation costs. This highlights the importance of financial and infrastructural considerations when introducing VR technologies into the educational system.

In conclusion, based on the five criteria, it can be summarized that ClassVR and zSpace demonstrate strong pedagogical potential, while Virbela stands out in terms of accessibility and usability. The comparative model suggests that the choice of platform should depend on the context: an educational institution that prefers digital simulations may opt for zSpace, whereas schools seeking scalable and cost-effective solutions may find Virbela more suitable. Therefore, the data support the conclusion that the effectiveness of integrating VR into secondary education depends not only on technological complexity but also on institutional capacity, educational objectives, and economic feasibility.

Analysis of AR applications

AR educational applications offer interactive and visually engaging learning opportunities by overlaying digital information onto the real world. These platforms stimulate the development of spatial thinking, creativity, and digital skills, while also supporting project-based learning and the visualization of abstract concepts (Zuo et al., 2025). Although AR applications provide a lower level of immersion than VR, they stand out for their greater accessibility and easy integration into the educational process, making them suitable for a wide range of academic disciplines, including economics. For the purposes of this study, three leading AR platforms were examined: Merge EDU, Assemblr EDU, and Quiver, each offering unique functionalities and pedagogical advantages tailored to the needs of secondary education (Fig. 2).

1. **Merge EDU:** developed as an educational AR platform focused on interactive and experiential learning through three-dimensional models and simulations. Its main goal is to facilitate the understanding of abstract concepts through the visualization and manipulation of objects in a real environment. It is suitable for STEM subjects but can also be adapted for economics education (e.g., visualization of production processes, value chains, and business infrastructure).

Tools: 3D models and holographic objects; Merge Cube (a physical tool for AR interaction); ready-made educational modules; virtual labs and simulations; teacher dashboard for content management

Results:

- increased student engagement and motivation;
- improved spatial and visual thinking;
- better understanding of complex concepts;
- effectiveness in project-based learning.

Advantages:

- high level of interactivity;
- supports active learning;
- suitable for simulations and modeling;
- integrates with curricula.

Disadvantages:

- requires additional hardware (merge cube);
- some content is paid;
- more limited ready-made economic topics;
- teacher training is necessary.

2. **Assemblr EDU:** an AR platform focused on creating your own content. It allows teachers and students to build interactive AR scenes and is particularly suitable for interdisciplinary and economic subjects (e.g., visualization of business models, markets, diagrams, and organizational structures). Its main goal is to stimulate creativity and project-based learning (PBL).

Tools: AR editor for scene creation; library of 3D objects; embedding text, video, and animation; QR codes for sharing; and online access (web-based environment).

Results:

- development of digital and creative competencies;
- increased student autonomy;
- improved visualization of educational content;
- support for collaboration and teamwork.

Advantages:

- very easy to use;
- suitable for economic disciplines;
- does not require specialized hardware;
- flexibility in content creation.

Disadvantages:

- lower level of "deep" interactivity;
- limited complexity of simulations;
- some features require paid access.

3. Quiver: an AR application that combines traditional coloring with digital visualization through augmented reality. The platform is primarily aimed at younger age groups but can also be used in secondary education for basic visualizations and introductory lessons. Its main goal is to stimulate interest in educational content through a game-based approach.

Tools: coloring templates (printable sheets); AR mobile application; animations and interactive scenes; and thematic educational packages.

Results:
- increased motivation and attention;
- development of visual-spatial perception;
- suitable tool for introductory lessons.

Advantages:
- very accessible and easy to use;
- low threshold for technical skills;
- suitable for quick demonstrations;
- high motivational value.

Disadvantages:
- limited applicability in economic education;
- low depth of academic content;
- more of a supplementary than a primary tool;
- mainly suitable for basic level.

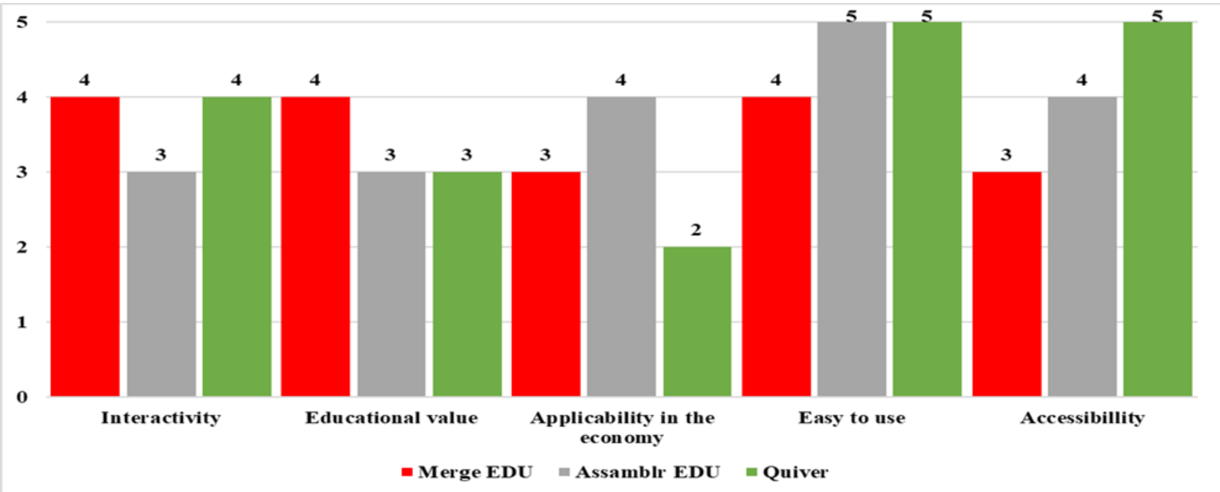

Fig. 2 Comparative analysis of AR platforms in education

Source: *Author's research*

Figure 2 presents a comparative assessment of three augmented reality (AR) platforms: Merge EDU, Assemblr EDU, and Quiver, based on five criteria: Interactivity, Educational Value, Applicability in economic education, Easy of use, and Accessibility. The evaluation is based on a five-point Likert scale (1 = low; 5 = high), allowing for a systematic comparison between the different platforms.

According to the "Interactivity" criterion, Merge EDU and Quiver received the highest scores (4 points each), while Assemblr EDU received a slightly lower score (3 points). This suggests that Merge EDU and Quiver offer more engaging and dynamic user experiences, thanks to interactive 3D visualization and real-time manipulation of digital objects. Assemblr EDU, although interactive, may rely more on structured content templates, which could limit spontaneous user exploration.

Regarding the "Educational value" criterion, two of the platforms scored equally at 3 (Assemblr EDU and Quiver), while Merge EDU led by a full point at 4. This distribution indicates that Merge EDU may offer stronger curriculum alignment or more structured pedagogical integration, while the other two platforms provide moderate but still significant educational benefits.

Among all five criteria for the AR platforms under review, the low score for "Applicability in economic education" for Quiver (2) is notable, representing the lowest value recorded across the five criteria. Assemblr EDU received the highest score (4), followed by Merge EDU (3). Based on these results, it can be inferred that Assemblr EDU may offer more adaptable tools for content creation, suitable for visualizing abstract economic concepts, such as market structures, production processes, or supply chains. Quiver, primarily designed for visualization through AR interactions based on coloring, appears less tailored to economic modeling specific to the discipline.

In terms of "Easy of use," Assemblr EDU and Quiver achieved the maximum score (5), followed by Merge EDU at 4. This shows that user-friendly interfaces and minimal technical requirements are a strong advantage for Assemblr EDU and Quiver, potentially facilitating faster adoption in the classroom and reducing teachers' workloads. The criterion of ease of use remains a critical factor for technology adoption, especially in secondary education, where pedagogical professionals possess varying levels of digital competence.

Apart from the "Applicability in economics" criterion, the next most significant differentiation is observed in "Accessibility." Quiver achieved the highest score (5), followed by Assemblr EDU (4) and Merge EDU (3). The high accessibility scores for Quiver and Assemblr EDU likely reflect their compatibility with standard mobile devices and lower infrastructure requirements, which enhance scalability in resource-limited educational settings.

Summaries and conclusions from Fig. 2:

- Merge EDU is a robust AR platform with significant interactivity and educational value, but lower scores for accessibility and applicability in economics education, requiring adaptation by educational professionals. It is suitable for schools with better technological infrastructure and professional teacher training.
- Assemblr EDU is the most versatile tool for economics education; easy to use and highly applicable, making it a suitable choice for integrating AR visualizations, economic models, and practical content without the need for complex preparation.
- Quiver, while the most accessible and user-friendly, appears more suitable for introductory or engaging applications rather than for advanced economic concepts.

These results show that the choice of platform should align with educational goals: institutions prioritizing accessibility and engagement may prefer Quiver, while those seeking discipline-oriented AR integration may benefit more from Assemblr EDU. The results underscore the importance of aligning technological functionality with specific learning objectives and institutional capacity when integrating AR solutions in secondary education.

Comparative assessment of the average values of VR/AR platforms

A comparative assessment of VR/AR platforms in secondary education reveals differentiated performance among immersive technologies. Based on the calculated average scores (Fig. 3), the platforms are ranked as follows:

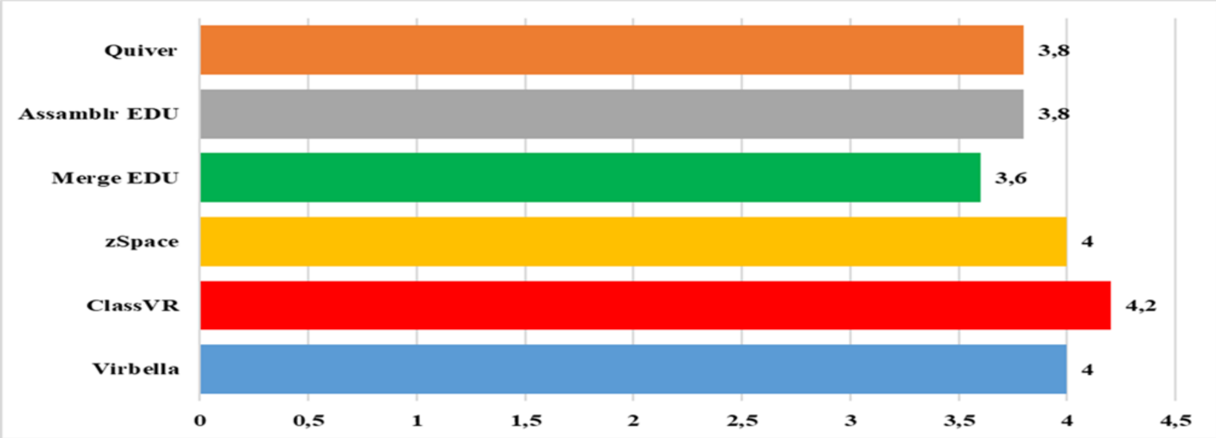

Fig. 3 Average scores of VR/AR platforms in education

Source: *Author's research*

The highest overall index was achieved by ClassVR (4.2), indicating strong performance in terms of interactivity, educational value, usability, and institutional applicability. The platform's immersive depth and structured educational ecosystem likely contributed to its composite score.

zSpace (4.0) and Virbela (4.0) demonstrated equal levels of effectiveness. zSpace is particularly strong in simulation-based and STEM-oriented immersive learning, whereas Virbela performs well in collaborative and virtual learning contexts, especially where communication and teamwork are pedagogical priorities.

Among the platforms focused on AR, Assemblr EDU (3.8) and Quiver (3.8) achieved moderate but balanced results. Assemblr EDU is characterized by flexibility and ease of content creation, whereas Quiver ranks high for accessibility and convenience. However, both platforms demonstrated lower immersive depths than VR-based platforms.

Merge EDU (3.6), while pedagogically robust and interactive, recorded the lowest overall index among the platforms reviewed. This may be attributed to moderate requirements for accessibility and infrastructure, which affect scalability in standard secondary schools.

Conclusion

The results reveal a clear pattern: fully immersive VR platforms generally achieve higher overall performance indices than AR-based tools, especially when evaluated through comprehensive educational integration. This suggests that immersion depth, structured content ecosystems, and hardware-supported engagement significantly enhance pedagogical effectiveness.

However, the difference between VR/AR platforms should not be interpreted solely as technological superiority. While VR platforms such as ClassVR and zSpace demonstrate stronger potential for immersive learning, they also require higher institutional readiness, financial investment, and digital competence among teachers. Their effectiveness is closely tied to systemic infrastructure and the capacity for professional development (Thangavel et al., 2025).

Conversely, AR platforms exhibit greater accessibility and scalability. Tools such as Assemblr, EDU, and Quiver are more adaptable in resource-constrained environments and allow for gradual digital integration. Although their intensity is lower, they offer flexibility and ease of adoption, which are critical factors for widespread implementation in secondary education systems (Velarde-Camaqui et al., 2024).

The comparative results also suggest that the institutional context mediates the technological impact. High-performing VR systems are most effective in schools with advanced digital infrastructure, whereas AR platforms can serve as transitional or complementary tools within broader digital transformation strategies (Zekeik et al., 2025).

From a strategic perspective, the analysis supports a differentiated deployment model:

- VR platforms for highly immersive, simulation-intensive, and collaborative learning environments;
- AR platforms for scalable, curriculum-integrated, and resource-efficient applications.

Overall, digital technologies demonstrate significant potential to enhance engagement, experiential understanding, and interdisciplinary learning. However, their successful integration depends less on technological novelty and more on pedagogical alignment, teacher preparedness, and sustainable institutional investment.

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