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ARIES

Augmented and immersive Reality for Improved Education in Schools in Europe

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Systematic literature review on the use of A&IR in education

Introduction

In recent years, the adoption of Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR) solutions has been increasing exponentially. In 2022, North America and Europe are leading the global market, which is valued at approximately $30 billion and is projected to reach $521 billion by 2031 (Damani, 2024). The availability of devices supporting AR/VR/MR is increasingly widespread. AR/VR/MR capabilities are now essential features of modern mobile phones, and VR headsets are available at affordable prices across various price ranges. The recent entry of Apple into the VR headset market with its Vision Pro could significantly boost the VR/AR/MR headset market, expanding its reach to a wider audience in the long term and promoting the use of these devices in everyday activities. In particular, Virtual Reality (VR) fully immerses the user in a digitally created environment, effectively replacing their perception of the real world with a simulated one (Bowman & McMahan, 2007). This is typically achieved through the use of head-mounted displays (HMDs), motion tracking, and interactive controls, allowing the user to interact with the virtual environment in a seemingly natural way.

Augmented Reality (AR) is a technology that overlays digital information, such as images, videos, or other data, onto the real-world environment in real-time (Azuma, 1997). This enhances the user's perception of the physical world by integrating computer-generated elements into their sensory experience. AR is typically experienced through devices such as smartphones, tablets, or AR glasses. Mixed Reality (MR) is a blend of physical and digital worlds, extending the concepts of both VR and AR by enabling a more immersive experience where real and virtual objects coexist and interact in real-time (Milgram & Kishino, 1994). MR environments are experienced through devices like the Microsoft HoloLens which provide spatial mapping and localization to integrate virtual objects into the physical environment convincingly.

Since the seminal articles by Azuma (Azuma, 1997) on Augmented Reality (AR) and Steuer (Steuer, 1995) on Virtual Reality (VR), the number of scientific papers focusing on the educational applications of these technologies has shown a positive and incremental trend (Avila-Garzon, Bacca-Acosta, Kinshuk, Duarte, & Betancourt, 2021; Karakus, Ersozlu, & Clark, 2019; Soto, Navas-Parejo, & Guerrero, 2019). From a theoretical perspective, researchers have questioned whether technologies such as AR, VR, and MR can serve as effective learning tools, emphasizing the role of the student as an active constructor of knowledge, engaged in interactive and meaningful educational experiences. Moreover, these technologies address the need to renew educational processes and engage 21st-century students (Drljević, Botički, & Wong, 2022) through techno-mediated methods similar to what teenagers are accustomed to in their leisure time. During adolescence, students spend an average of about eight and a half hours on screen media (Rideout, Peebles, Mann, & Robb, 2022), primarily engaged in social media and gaming activities (Vogels, Gelles-Watnick, & Massarat, 2022).

As detailed in the following paragraph, numerous systematic reviews on the use of AR, VR, and MR in education have been published. To the best of our knowledge, none of these reviews simultaneously cover AR, VR, and MR with a specific focus on secondary schools. The decision to investigate the existing literature on a broad range of virtual technologies for secondary school settings is driven by the goal of supporting secondary school teachers in applying innovative learning approaches based on methodologies, technologies, and educational content that reflect current scientific advancements. Therefore, the present systematic review poses the following research questions:

- RQ1. What types of technologies (e.g., VR headset, helmet, Optical Head-Mounted Display (OHMD), Head-Mounted Display (HMD), Handheld Device, smart glasses) are used in the context of AR/VR/MR to support educational processes in secondary schools?
- RQ2. What theoretical approaches underlie the use of AR/VR/MR to support educational processes in secondary schools?
- RQ3. What are the goals of introducing AR/VR/MR technologies to support educational processes in secondary schools (e.g., learning, motivation, addressing learning difficulties, inclusion)?
- RQ4. What are the limitations (e.g., environmental sustainability, cost, difficulty of implementation) of using AR/VR/MR technologies to support educational processes in secondary schools?
- RQ5. What is the impact of AR/VR/MR technologies on educational processes in secondary schools, as evaluated through statistical analyses of studies that assess changes in constructs following the introduction of these technologies?

This scientific work is one of the outputs of the Erasmus+ Augmented and Immersive Reality for Improved Education in Schools in Europe (ARIES) project (2023-1-IT02-KA220-SCH-000159590).

Related work

Among the technologies considered in the systematic reviews, AR emerged as the most investigated in the context of education within the secondary education age range, compared to VR and MR. Some reviews, such as Saltan (Saltan & Arslan, 2017), highlighted the potential educational outcomes of AR applications and the challenges of effectively integrating emerging technologies. Yin (Yin, Li, Deng, & Luo, 2022) reviewed 69 papers focused on K16 education, identifying a growing trend in AR use, particularly in science education. This focus on science subjects is also predominant in Pellas' review of the use of AR in game-based learning (Pellas, Fotaris, Kazanidis, & Wells, 2019) and immersive virtual reality (IVR) supporting STEM education (Pellas, Dengel, & Christopoulos, 2020). This trend is likely driven by the fact that science subjects lend themselves to solutions where elements that would otherwise need to be imagined can be visualized, reducing the need for laboratories or sophisticated technological equipment in schools.

Other reviews, such as Masneri (Masneri, Domínguez, Zorrilla, Larrañaga, & Arruarte, 2022), provided insights into the importance of collaborative AR educational experiences, while Quintero (Quintero, Baldiris, Rubira, Cerón, & Velez, 2019) emphasized the importance of considering inclusion when using these technologies for educational purposes.

Pellas' review on IVR in K12 education (Pellas, Mystakidis, & Kazanidis, 2021) highlighted the connections between the quality of the technology used and the educational processes implemented. More affordable technologies were associated with more passive instructional approaches compared to HMDs. However, the authors noted that cutting-edge technology does not necessarily lead to more effective learning outcomes. In fact, the more promising learning affordances of IVR for educational purposes in K12 education are not directly tied to the quality of the technology itself, as identified in a review by Di Natale (Di Natale, Repetto, Riva, & Villani, 2020). The review highlights how first-hand immersive experiences, regardless of the technology's sophistication, can foster motivation, engagement, and enhance cognitive, psychomotor, and affective skills.

The cited systematic reviews do not report only positive effects of virtual technologies; the impact of these technologies is often controversial. One major concern is the lack of strong theoretical approaches, as noted by Hamilton (Hamilton, McKechnie, Edgerton, & Wilson, 2021), and the limited variety of educational methods used, highlighted by Saltan (Saltan & Arslan, 2017). Additionally, there is the risk of cognitive overload in students when using immersive technologies, as emphasized by Pellas (Pellas et al., 2021). Other challenges include small sample sizes in studies (Quintero et al., 2019; Saltan & Arslan, 2017), the high costs of technological devices, and the difficulty teachers face in managing technological glitches (Pellas et al., 2020).
In contrast to these previous reviews, the goal of our study is to identify educational practices using AR, VR, and IR specifically in secondary education, evaluating how these techno-mediated educational experiences can be integrated into classrooms in a feasible and effective manner. The study aims to support educators in applying innovative approaches with accessible resources, ensuring that the practices identified are practical and easily replicable in diverse educational contexts.

Results

The distribution of papers on AR/VR/MR in secondary schools over the past 10 years described in Figure 1 has shown a positive trend, with a general increase in the number of articles each year. However, exceptions occurred in 2019 (N = 3) and 2021 (N = 3), likely due to the global COVID-19 pandemic, which disrupted many in-school educational activities. The spike in publications in 2020 (N = 10) could be explained by the time required to write, review, and publish scientific papers, meaning that many of the studies published in 2020 likely reflect educational experiences conducted before the pandemic-related lockdowns.

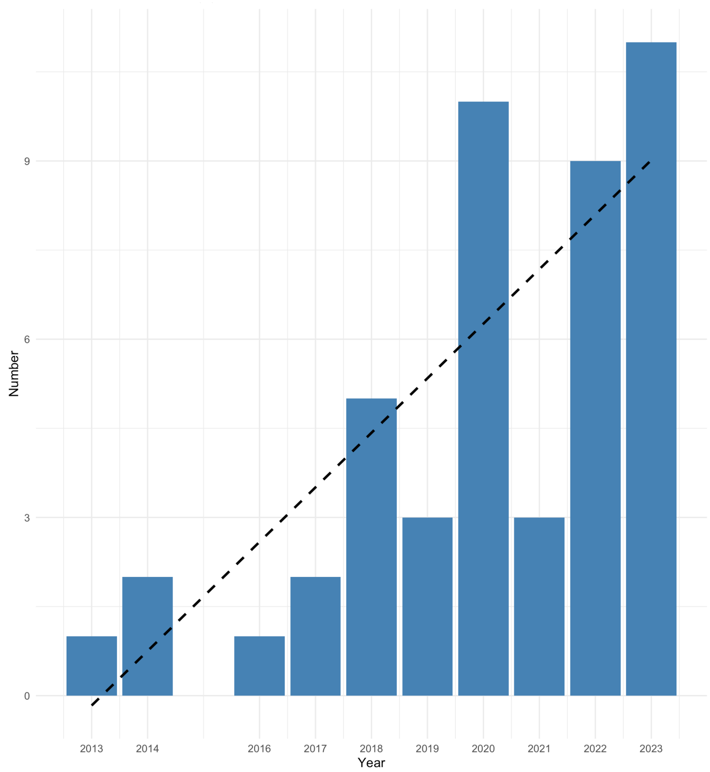

Figure 1. Distribution of papers by publication year

Figures 2 and 3 present the distribution of papers based on the country of origin of the first author. The leading countries in research on AR/VR/MR applied to secondary school settings are Turkey (N = 7), followed by China and Malaysia (both N = 4). Overall, the majority of research is concentrated in Asia and Europe, accounting for approximately 85% of the reviewed papers.

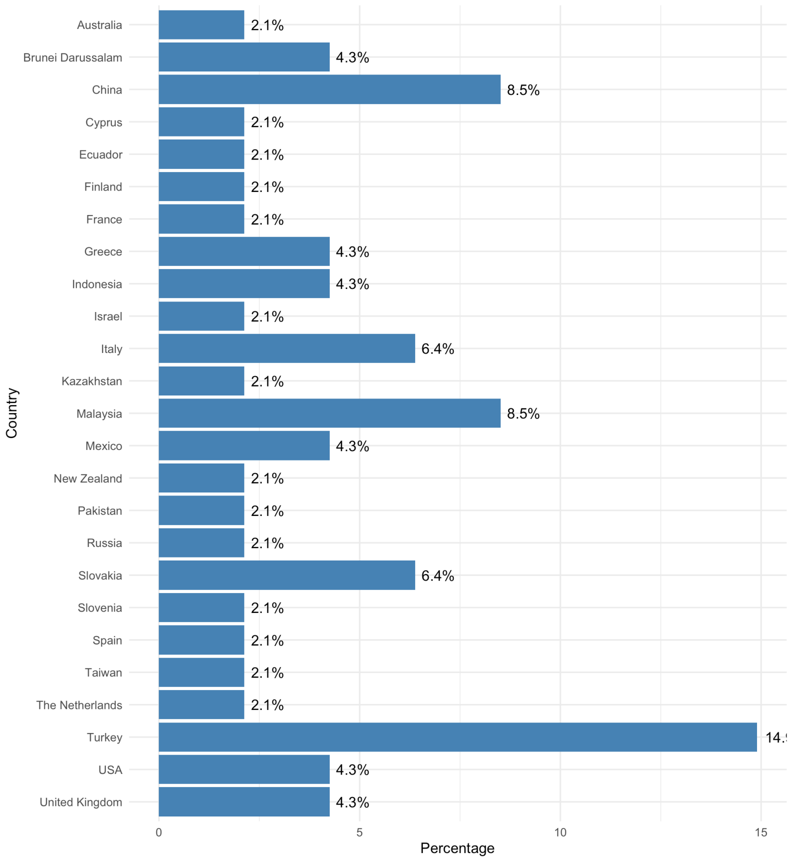

Figure 2. Distribution of papers per country

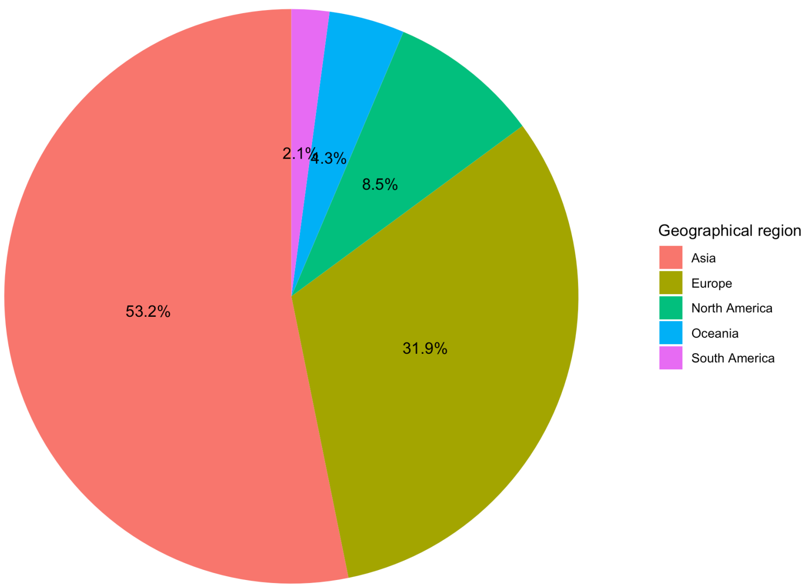

Figure 3. Percentage of papers per geographical region

Each of the included studies was examined to identify the subjects where AR/VR/MR technologies are applied in secondary education. As expected, topics related to science (N = 18), mathematics (N = 7), and computer science (N = 3) are the most represented, comprising approximately 63% of the studies. This is likely due to the specific affordances of AR/VR/MR technologies, which allow students to interact with concepts and phenomena that would otherwise remain abstract. Additionally, virtual technologies enable learners to experiment with dangerous processes without the need for expensive equipment or the risk of personal harm. Virtual technologies are also used to support the teaching of social sciences, particularly in subjects like history (N = 5), geography (N = 2), and tourism-related topics (N = 1).

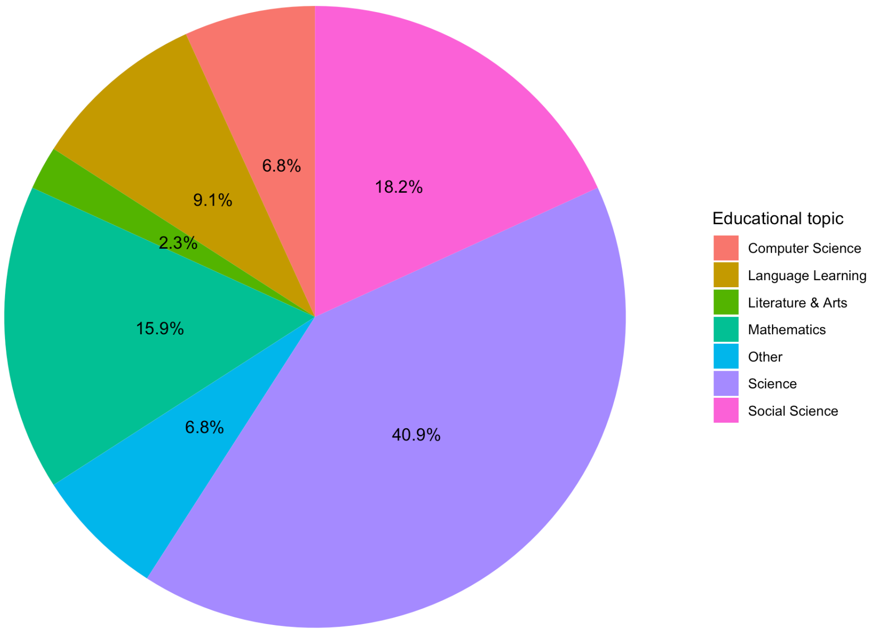

Figure 4. Studies by educational topic

The sample size of the selected studies is in line with the results identified by Bacca et al. (Bacca, Baldiris, Fabregat, Graf, & Kinshuk, 2014) for AR research, with the majority of studies (66%) involving between 30 and 200 participants. A smaller portion of studies included fewer or equal to 30 participants (23%), and only one study involved more than 200 participants (2%). Additionally, 4 studies did not specify the sample size (8%). Fortunately, this distribution is slightly better than that observed by Quintero et al. (Quintero et al., 2019) in AR use for inclusive education, where most studies involved samples of ten or fewer individuals.

Methodology

The current systematic review respects the guidelines outlined in the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement (Page et al., 2021).

Eligibility criteria

Inclusion criteria for this review comprised articles published in peer-reviewed scientific journals or conference proceedings relevant to the fields of education and technology. Additionally, articles had to describe or evaluate the use of AR/VR/MR technologies in educational processes, ideally reporting on technological features, theoretical approaches, educational goals, limitations, and/or the quantitative or qualitative impact of AR/VR/MR technologies on learning within school settings.

Given the rapid technological development in the domain of AR/VR/MR, articles from the past 10 years (2013-2023) were selected for inclusion.

Exclusion criteria were applied to filter out articles not relevant to the research questions or those addressing other levels of education. Articles that did not provide sufficient information on the methodology, results, or implications of AR/VR/MR technologies were excluded. Furthermore, studies with obvious conflicts of interest, methodological errors, or ethical violations were not considered.

Duplicate articles or those reporting the same data as other studies already included were also excluded.

Search strategy

The initial search yielded 600 articles: 20 from PubMed, 187 from Scopus, 142 from Web of Science, and 251 from IEEE.

The search for articles included four scientific databases, focusing on educational and technical domains: Pubmed, Scopus, Web of Science, IEEE.

Each search engine has been questioned using the following keywords combined with a boolean logic, asking for:

("Augmented Reality" OR "Immersive Reality" OR "Virtual Reality") AND ("Secondary School")

The extraction of full-text scientific articles was conducted on January 12, 2024.

Selection process

The first author of the current systematic review extracted the initial data from the research search engines in CSV format and then merged the datasets with the support of a custom R script. This script was designed to remove initial duplicates and to extract missing abstracts from the web using the DOI of each paper and the "rcrossref" package (Chamberlain, Zhu, Jahn, Boettiger, & Ram, 2022). Subsequently, three independent reviewers screened the papers to verify the compliance of each article with the inclusion and exclusion criteria, initially based on the title and abstract, and then by accessing the full text. At each step of the analysis, the reviewers discussed to clarify any cases where they disagreed about the eligibility of the articles.

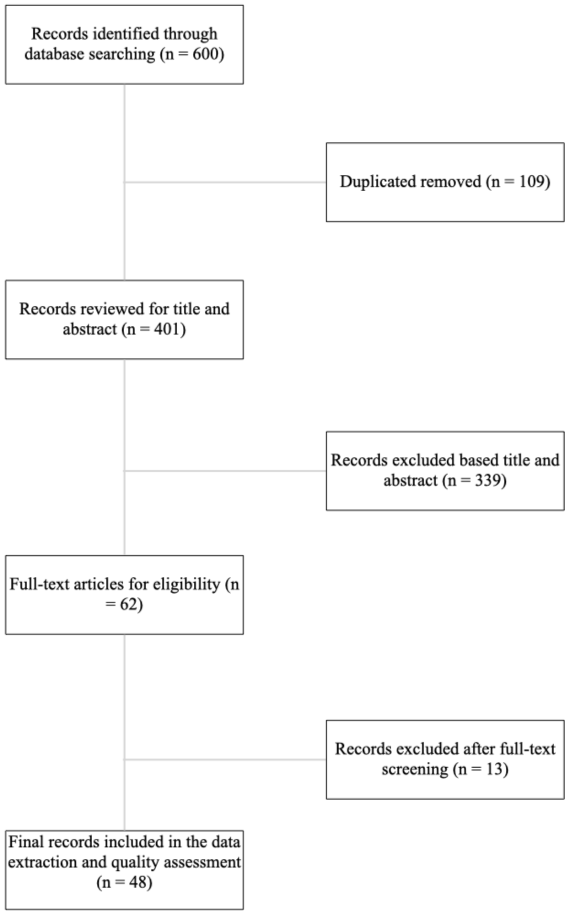

Figure 5. Process of selection of scientific papers

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