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Duality in barriers and enablers of augmented reality adoption in education: a systematic review of reviews

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Abstract

Purpose – The study aims to identify the key advantages/enablers and disadvantages/barriers of augmented reality (AR) implementation in education through existing reviews. It also examines whether these factors differ across educational domains.

Design/methodology/approach – This study conducted a systematic review of reviews to synthesize evidence on the barriers and enablers influencing AR adoption in education. Searches were performed across five databases, with 27 reviews meeting the inclusion criteria. Data extraction and quality assessment were completed. Content analysis was conducted using the AR adoption factor model and consolidated framework for implementation research.

Findings – The findings reveal several enablers such as pedagogical benefits, skill development and engagement. Equally, multiple barriers were identified, including high costs, technical issues, curriculum design challenges and negative attitudes. Interestingly, duality emerged, whereby some factors served as both barriers and enablers depending on the educational context.

Originality/value – This review contributes a novel synthesis of the complex individual, organizational and technological factors influencing AR adoption in education across diverse domains. The identification of duality factors provides nuanced understanding of the multifaceted dynamics shaping AR integration over time. The findings can assist educators in tailoring context-sensitive AR implementation strategies to maximize benefits and minimize drawbacks. Further research should explore duality factors and their interrelationships in AR adoption.

Keywords Systematic review of reviews, Augmented reality, Barriers, Enablers, Duality, Education, Implementation

Paper type Literature review

Introduction

Augmented reality (AR) refers to a technology-based system that adds virtual data or objects to a real-world environment in real time by mixing real and virtual content. The physical environment is enhanced and modified by AR; thus, AR experiences are driven by the experience of digital content within a physical space (Rauschnabel *et al.*, 2022). Such a system

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may be used in a variety of everyday circumstances in practically every business (e.g. education, health care, tourism, retail, maintenance, construction and sports), thereby providing value, enhancing the user's experience and resolving issues (Xanthidis *et al.*, 2020). Particularly in the education sector, it provides opportunities and possibilities for every age group and education level by establishing new learning experiences that allow students to interact with learning content in creative ways (Cerrato *et al.*, 2018; Xanthidis *et al.*, 2020).

AR enables versatile applications to enrich educational experiences across several dimensions. For example, AR-enhanced books introduce interactive elements, making reading more engaging and immersive, while providing supplementary information (Elmunsyah *et al.*, 2019; Hossain *et al.*, 2019). AR gaming, with its immersive and interactive experiences, incentivizes learners to explore and discover new concepts and hone skills such as critical thinking and collaboration (Marques and Pombo, 2021). AR also contributes significantly to discovery-based learning, fostering self-acquired knowledge through exploration and enquiry by offering rich contexts and scaffolded guidance (Almaadawy, 2019; Behzadan and Kamat, 2013). Additionally, AR enhances object modeling and simulations, permitting learners to create and manipulate digital models of tangible or abstract objects in a realistic and intuitive manner, helping to visualize complex phenomena (Indalkar *et al.*, 2017; Yuen *et al.*, 2011). It also aids in skill training, focusing on competency development by immersing learners in realistic scenarios and providing performance feedback (Chang *et al.*, 2020; Elfeky and Elbyaly, 2021). Finally, AR is beneficial for assessment and guidance, measuring and bolstering learner performance and progression by delivering immediate, personalized feedback and tailoring learning paths (Lin *et al.*, 2015; Shirazi and Behzadan, 2015).

Despite the reported success of AR, the assessment of its true impact remains complex because of the novelty and diversity of its applications and the combination of factors that influence outcomes (Marques and Pombo, 2021). AR promotes active learning, notably for underperforming students, by improving academic achievement in various subjects, enhancing critical thinking skills and fostering a learner-centered classroom environment (Saidin *et al.*, 2015). In health education, AR introduces an immersive and interactive exploration of human anatomy, supporting safer and more effective medical training (Campisi *et al.*, 2020). On the other hand, AR has significantly influenced STEM education, aiding the visualization and understanding of complex concepts in mathematics, engineering, programming and science while also encouraging student engagement and interactive learning (Boboc *et al.*, 2021; Tomaschko and Hohenwarter, 2019). Beyond STEM and health, AR applications are deployed in diverse fields to enhance instruction, serving as an immersive tool for historical or artistic illustrations, an efficient means for personalized student assessment and a platform for fostering collaboration and critical thinking (Faridi *et al.*, 2021).

The implementation of AR has been researched in various cases and locations (Zhou *et al.*, 2022). In the past decade, an increasing number of studies have demonstrated that education is one of the most promising application areas for AR (Ibáñez and Delgado-Kloos, 2018). The growth of AR and its use in formal (e.g. universities and schools) and informal (e.g. workplaces) learning environments have been reported. According to Ducasse (2020) and Petrovich *et al.* (2018), AR facilitates learning both inside and outside schools to assist formal and informal learning contexts by designing new everyday learning experiences. However, implementing new technology in classrooms is a challenging process that involves multiple steps. This includes developing and creating ways to use technology to support curriculum and teaching techniques (Aso *et al.*, 2021), an assessment of its effectiveness, including the opinions of key stakeholders (Buhl, 2017), and, if it proves beneficial, wider adoption can be implemented (Alkhattabi, 2017). The adoption of new technologies such as AR is often driven by enabling factors and demonstrable advantages. Similarly, barriers and disadvantages may impede their adoption.

The growing use of AR in educational and learning contexts has resulted in many systematic and structured reviews. For example, a systematic literature review (SLR) by Alzahrani (2020) investigated the use of AR in e-learning and explored its benefits, trends, advantages and challenges. With a slightly different perspective, Ibáñez and Delgado-Kloos (2018), Sırakaya and Sırakaya (2022) and Ajit *et al.* (2021) explored AR benefits, challenges and developments in STEM education. Similarly, Garzón and Acevedo (2019) assessed the impact of AR on learning effectiveness. In addition, several SLRs had specific objectives, including those carried out by Akçayır and Akçayır (2017), focusing on how AR has been assessed in the education field. The SLR presented by Radu and Schneider (2019) analyzed articles that compared AR and non-AR applications, while numerous reviews focused specifically on medical education. Recent systematic reviews have been conducted on surgical education (Sheik-Ali *et al.*, 2019), neuronavigation (Cho *et al.*, 2020), radiology (Uppot *et al.*, 2019) and anatomy (Chytas *et al.*, 2020). Despite covering several aspects related to AR use in education, none of these systematic reviews concentrated on barriers to AR adoption in education across domains, and they did not always agree on the benefits, challenges and effectiveness of AR.

The present study focused on the barriers and/or enablers of AR use in education. This review takes a global perspective and considers its use across broad educational domains. In this way, the review contributes to a novel synthesis of the complexities of AR use in educational settings that encompasses cross-cultural and domain specifics not captured in reviews with more restricted focus. This is relevant to those considering AR implementation in countries with a lower usage of immersive technologies in education. For example, Saudi Arabia, where educator adoption lags despite higher authority, claims that AR is available and is expected to be adopted (Alkhattabi, 2017).

Broadly, barriers/enablers and advantages/disadvantages fall within specific categories. In the current review, the authors identified the following categories: associated with usage, associated with skills acquisition and environmental context and resources. These categories are divided into subcategories, followed by related benefits/enablers and disadvantages/barriers. Additionally, there are relationships between adjacent barriers/disadvantages and enablers/advantages across the model, where some barriers/drawbacks can be mapped to the corresponding enablers/advantages. These identified categories are considered as "AR adoption factor model" (AR-AF model), which is used to consider the research analyzed in this current study.

In the context of AR-AF model identified in the current review, the categorization of barriers and enablers, as well as advantages and disadvantages, is essential for a comprehensive understanding of AR implementation in educational settings. This model aids in discerning the key elements affecting AR adoption and in developing tactics for its efficacious application in educational settings. This model not only facilitates the understanding of specific factors influencing AR adoption but also aids in creating strategies to enhance its effective use in education.

One of the challenges faced by researchers and policymakers who confront many reviews on the same issue is the inconsistency of review findings and conclusions. Tranfield *et al.* (2003) provided direction on how to resolve contradictory results in individual studies, noting that a systematic evaluation of reviews will aid in addressing this issue. A systematic review of reviews helps ensure consistency in the outcomes of individual reviews. Because existing AR reviews differ in terms of scope, quality and conclusions, it is difficult to determine barriers to AR use in education in general terms. Thus, we conducted a systematic review of reviews, as recommended by Smith *et al.* (2011), to address these issues. The goal of the work presented here was to provide a comprehensive review of the barriers and enablers of AR use in educational settings and, specifically, to identify adoption factors that may differ according to the educational context. The results of the review were synthesized based on the consolidated framework for implementation research (CFIR) and provide advice and recommendations for the future adoption of AR in education. CFIR provides a systematic way to understand which parts are important for implementation and where more research is needed.

The conceptual framework from Damschroder *et al.* (2009), the CFIR, allows systematic assessment of the contexts in which multiple levels of implementation are taking place to identify factors that may affect intervention implementation and effectiveness at each level. It is an approach to understanding a phenomenon that involves the systematic illustration or description of the key elements, constructs or variables influencing it. CFIR is a useful tool for guiding rapid-cycle evaluations of the implementation of AR applications in education. As an evaluation tool to inform the key stakeholders about developments in the intervention and its implementation, the CFIR can be used to gather data during the initial stages of implementation. According to Damschroder and Lowery (2013), the CFIR can be used as a tool for explaining variation in intervention implementation, as well as measuring the impact of CFIR constructs on intervention implementation across studies. While we are unaware of any examples applying this framework to systematically analyze implementation barriers and enablers for rapid-cycle assessment to multiple contexts and implementations at the same time, we adapt the five major domains of the framework here to provide an appropriate lens for the synthesis of the results of the review.

There are five major domains in the CFIR, each of which may affect the implementation of a given intervention (Damschroder *et al.*, 2009):

(1) *Intervention characteristics* or features that may influence implementation of an intervention. Intervention characteristics include eight constructs (e.g. cost, complexity and design quality).

(2) *Inner setting*, organizational features that may affect implementation of the intervention. Inner setting consists of 12 constructs (e.g. leadership engagement, resources availability and relative priority).

(3) *Outer setting*, which refers to various aspects of the external environment or context that might affect implementation. The outer setting consists of four constructs (e.g. user needs and resources, peer pressure and external policy and incentive).

(4) *Characteristics of individuals*, which are factors that influence implementation of the intervention by individuals involved in its implementation. Characteristics of individuals are associated with five constructs (e.g. self-efficacy, knowledge and beliefs about the intervention and individual stage of change).

(5) *Process*, which may influence implementation through various strategies or tactics. The implementation process involves eight constructs (e.g. planning, engaging the key stakeholders in the implementation process and reflecting and evaluation).

According to Damschroder *et al.* (2009), the CFIR framework is flexible and customizable, and researchers can adapt the framework to the specific intervention factors, design and context under study by modifying it according to their specific study. The adoption of the CFIR in this research enables a comprehensive and flexible approach to systematically identify and assess factors that influence the implementation of AR applications in education.

Methodology

For this study, a systematic review of reviews was chosen as the appropriate method, as the number of reviews on AR use in educational settings has grown in recent years, and there is extensive primary research in the field, which would make synthesis difficult and time-consuming. A systematic review of reviews has the advantage of providing a comprehensive overview of evidence from several levels, including the combination of different interventions and diverse populations in different regions. Bringing separate reviews together and comparing them allow for the generation of new insights throughout the literature and the synthesis of a large body of work into a clear overview.

Selection of articles

A systematic search was conducted to find reviews in the literature on barriers to AR adoption in education. The Preferred Reporting Items for Systematic Reviews and Meta-analyses (Moher *et al.*, 2015) were modified for this study. The search strategy involved electronic searches in five major databases: ACM, Scopus, EBSCO, IEEE and ScienceDirect, covering sciences, social sciences, life, health sciences, computing and engineering. The inclusion timeframe of this review was all reviews published from 2017 to 2022. The timeframe for this review was chosen because of the recent increase in the use of AR with advanced devices, particularly since 2016, as mentioned in the Horizon Report (2017). To ensure that all reviews covered these advancements, we selected 2017 as the starting point for this review. Peer-reviewed studies were selected during the inclusion period because they were the most accurate, recent and extensive.

Specification of research question

The following research questions were defined to identify the most relevant literature for this study:

- *RQ1*. What benefits and/or enablers have been identified through the existing reviews of AR implementation in education?
- *RQ2*. What challenges and/or barriers have been identified through the existing reviews of AR implementation in education?
- *RQ3*. Do the reported barriers/enablers differ across educational domains?

Identification of articles

Because scholars in the field tend to use the keywords "augmented reality" and "AR" interchangeably, the researchers used both keywords combined with the Boolean operator "OR" to identify relevant results regarding AR in education. Although virtual reality (VR), mixed reality (MR) and extended reality (XR) often co-occur with the discussion of AR, the researchers narrowed the scope by focusing only on AR and did not include VR, MR or XR in the search terms. Gavish *et al.* (2015) mentioned that while these concepts are related, they achieve their goals in different ways, which is why their applicability in academic settings can vary significantly. Several other terms, including "barrier* OR obstacle* OR limit* OR challeng* OR difficult*," "education OR learn* OR teach* OR train*" and "review" were used to identify relevant reviews. The term "review" was used to narrow the search results to retrieve review papers, as some databases do not have this option in their filter features. The process of determining the articles that are relevant to this review has two stages. The first step removes duplicate papers and obviously irrelevant papers. We then independently reviewed the abstracts and titles of all retrieved articles, followed by a second full-text review of each article, if deemed relevant and eligible for further review. The process of resolving conflicts in determining the relevance of articles for this review involved a systematic and collaborative approach. Where a discrepancy occurred in the double-blind review process, it was discussed in frequent meetings dedicated to conflict resolution.

During these meetings, each party presented their argument for the inclusion or exclusion of the contested articles, citing specific reasons based on the criteria set out in Table 1.

Data coding and analysis

Using the Covidence platform (Covidence – Better Systematic Review Management, 2022), the researchers analyzed all reviews that met the inclusion criteria and performed a content analysis to identify patterns regarding the advantages and barriers of using AR in educational contexts. Relevant data were extracted from the reviewed articles based on the research objectives and questions.

Quality assessment

We evaluated the quality of the included reviews using the Critical Appraisal Skills Programme (CASP) tool (CASP UK, 2018). The CASP systematic review checklist allows for a more detailed discussion of the potential methodological challenges. This form was modified to include the following domains: review questions, inclusion and exclusion criteria, search strategy, quality assessment, results and review value. According to the evaluation, the quality was rated as high, medium or low. Quality assessment of the reviews did not result in any exclusion.

Data extraction and synthesis

Data gathering. Considering the appropriate synthesis, the data were extracted using carefully designed forms on the Covidence platform. A descriptive summary chart was created using data from the extracted studies to address the objectives and research questions explained in the introduction. A draft chart template is developed to ensure efficient data coding. Throughout the analysis, the charting form remained open to allow editing and incorporation of unforeseen data, allowing for an iterative process. This charting form included key items such as the author, year of publication, guidelines followed in the study, education field, key findings, number of studies included in the review, benefits/enablers and challenges/barriers and limitations.

Table 1. Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
AR must be the focus of the review	AR is not the focus of the review
Must be a review paper (systematic review, meta-analysis, scoping review and mapping review)	It does not mention AR in the title or abstract
The author(s) must consider barriers or enablers to AR use	It does not consider barriers or enablers to AR use
Only reviews in which full text can be obtained will be included (i.e. published in a peer-reviewed journal)	It is not a review
Should consider education applications	The most recent and/or complete review report will be chosen if the same authors published multiple versions of the same review
The reviewers used defined criteria to include and exclude primary research	No full text available
Must be written in English	Systematic reviews that have significant limitations or insufficient detail (e.g. no inclusion or exclusion criteria) to support repeatability

Source: Developed by the authors

Data synthesis. The current investigation demonstrates that the AR-AF model serves as a valuable instrument for aiding the deployment of the CFIR framework to ascertain the obstructions and catalysts of AR integration within the educational context. The AR-AF model offers an exhaustive and systematic classification of variables influencing the usage of AR across diverse educational territories, grounded on three principal categories: usage-related, skills acquisition-related and environmental context and resources-related.

The initial phase necessitated a thorough reading of the full text, extraction of the benefits or facilitators and detriments or hindrances and their subsequent categorization under the AR-AF model's categories. In the subsequent phase, these categories and their subcategories were mapped onto the domains and constructs embodied by the CFIR framework. This method allows for the identification of factors inherent to each domain and their interplay with the procedure and results of AR-based interventions. This signifies that the AR-AF model can equip both researchers and practitioners to leverage the CFIR framework more effectively and efficiently to comprehend and assess the execution of AR in the realm of education.

Results

Search results

In Phase 1, 498 studies were identified with 64 duplicated articles identified and removed, leaving a total of 434 unique papers. Phase 2 involved the rejection of 259 records and acceptance of 175 records based on title and abstract screening using the inclusion and exclusion criteria. In Phase 3, 175 selected papers were subjected to a full-text review; 148 papers were rejected and 27 were accepted (Figure 1). A total of 27 reviews were analyzed in this SLR (Supplementary I).

Description of the included reviews

Interestingly, all included reviews were published between 2019 and 2022, appearing in 23 different journals. Of these, 11 papers were published in Q1 journal, 11 in Q2, 3 in Q3, 1 in Q4 and 1 unknown, which provides an indication of the contribution of the work included and the relevance of literature on AR in education to their respective fields. Our analysis revealed that most studies focused on health education (11); however, six articles were more general in context, which provides an indication of the contribution of the work included and the relevance of literature on AR in education to their respective fields (Figure 2).

Augmented reality advantages/enablers and disadvantages/barriers

For detailed analysis, both advantages/enablers and disadvantages/barriers were categorized into three main groups. The first category is "associated with usage," where all subcategories are related to factors associated with actual AR implementations and uses. The second is "associated with skills acquisition," capturing advantages/enablers and disadvantages/barriers related to the skills acquired using AR in education. Finally, "environmental context and resources" capture factors related to the physical and technological environment for AR use. Each category had associated subcategories (Tables 2 and 3).

RQ1. What benefits and/or enablers have been identified through the existing reviews of augmented reality implementation in education?

AR technology has been noted for its transformative impact in the educational sphere, with significant advantages identified in the areas of curriculum design and learner experience

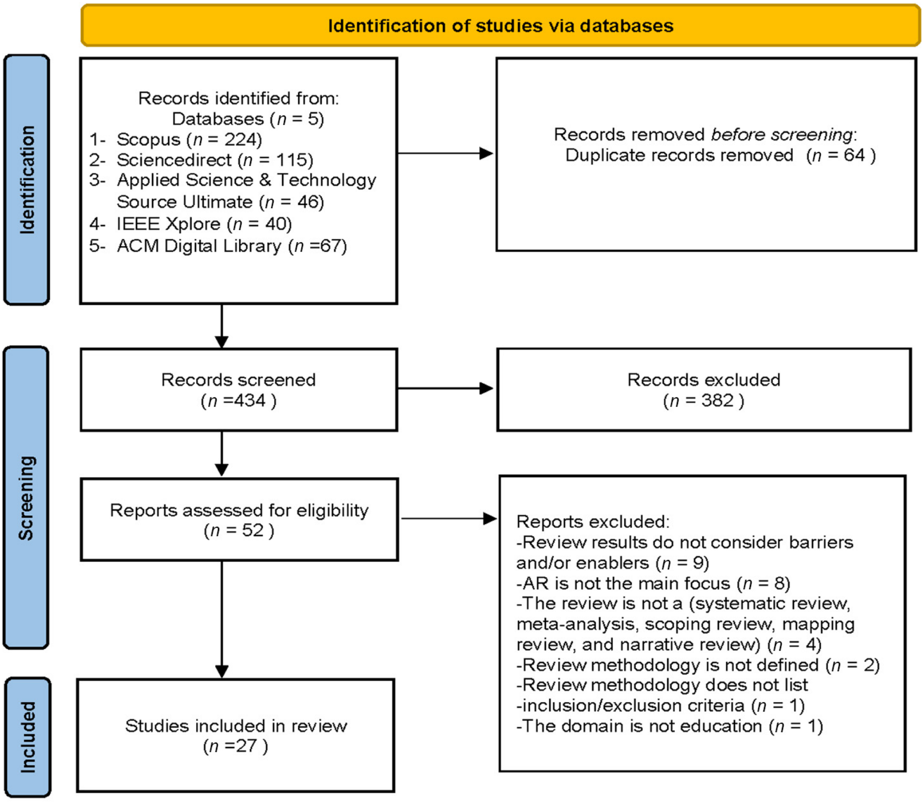

Figure 1.
PRISMA diagram for the study

Source: Developed by the authors

(Table 2). AR allows instantaneous feedback, enabling students to swiftly identify and correct their shortcomings (Kharvari and Kaiser, 2022; Theodoropoulos and Lepouras, 2021). Ahmad and Junaini (2020), Buentello-Montoya *et al.* (2021) and Muñoz *et al.* (2022) found that AR fosters both collaborative and independent learning, granting students autonomy in their educational journey. Additionally, AR's role in personalizing the learning approach was noted by Alzahrani (2020), Quintero *et al.* (2019) and Sırakaya and Sırakaya (2022), focusing on individual needs and accommodating various learning styles and attitudes and promoting interaction without constant oversight (Theodoropoulos and Lepouras, 2021). Reviews by Fernández-Batanero *et al.* (2022) and Samad *et al.* (2021) reported increased motivation and comprehension rates among students using AR. Furthermore, Dhar *et al.* (2021) and Rodriguez-Abad *et al.* (2021) found AR to be particularly beneficial in health education, making the study of anatomical structures more accessible through 3D representations.

The benefits of AR include improving performance, enhancing the acquisition of skills and facilitating knowledge transfer. AR use in classrooms has been linked to increased academic achievement and task accuracy (Ajit *et al.*, 2021; Garzón *et al.*, 2019; Samad *et al.*, 2021). In medical training, Cho *et al.* (2020) and Ha *et al.* (2021) observed that AR contributes to reducing surgical errors and optimizing surgical time, thereby enhancing surgical

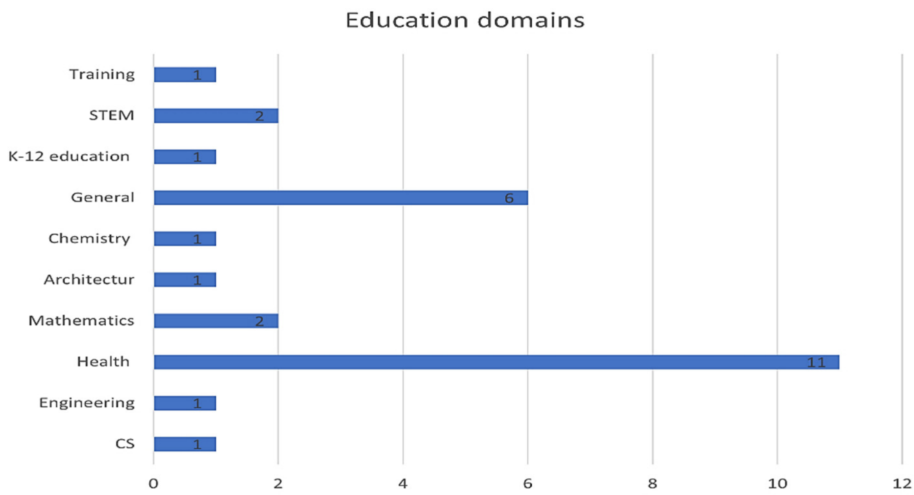

Figure 2. Educational domains for identifying papers

Source: Developed by the authors

precision. Mazzuco *et al.* (2022) and Parsons and MacCallum (2021) found that AR boosts concentration and knowledge retention, making learning more time-efficient. From the perspective of skill development, Dhar *et al.* (2021), Gasteiger *et al.* (2022) and Sırakaya and Sırakaya (2022) demonstrated AR's role in enhancing cognitive abilities. Additionally, Diao and Shih (2019) and Quintero *et al.* (2019) found that AR aids in the development of practical skills. The AR technology has also been linked to fostering creativity, as evidenced in the works of Ahmad and Junaini (2020), Kharvari and Kaiser (2022) and Theodoropoulos and Lepouras (2021). Furthermore, Garzón and Acevedo (2019) and Mazzuco *et al.* (2022) highlighted that AR provides an interactive environment for students to rehearse various scenarios safely, without real-life consequences. This immersive experience not only promotes a better understanding and retention of knowledge but also encourages creativity and innovation in learning processes.

AR technology has significant implications in terms of resource utilization and the environmental context. Ha *et al.* (2021), Martins *et al.* (2021) and Quintero *et al.* (2019) emphasize that AR reduces costs associated with physical resources such as lab equipment. Diao and Shih (2019) found that AR enhances the graphic capabilities of engineering students, making learning experiences more engaging and effective. Kharvari and Kaiser (2022), Muñoz *et al.* (2022) and Parsons and MacCallum (2021) observed that the ease of use of AR technology encourages its adoption among educators and students. Alzahrani (2020), Law and Heintz (2021), Mazzuco *et al.* (2022) and Rodriguez-Abad *et al.* (2021) associate AR with increased satisfaction in individual learners and educators because of its interactivity, reduced cognitive load and improved efficiency. In the context of safety in education, especially in medical fields, Innocente *et al.* (2022), Joda *et al.* (2019) and Martins *et al.* (2021) have highlighted AR's potential to revolutionize safety by allowing the safe execution of hazardous trials under realistic conditions. Moreover, AR increases information accessibility and facilitates remote learning, providing engaging training environments beneficial in both formal and informal educational settings (Garzón *et al.*, 2019; Gasteiger *et al.*, 2022).

Sub-category	Advantages/enablers	Related advantages/enablers	Sample references
Associated with usage			
Curriculum	Direct feedback		Theodoropoulos and Lepouras (2021)
	Stimulates collaborative learning and self-learning	No need for constant supervision	Buentello-Montoya *et al.* (2021)
	Student-centered learning		Alzahrani (2020)
	Individualized teaching		Sırakaya and Sırakaya (2022)
	Enhances learning delivery and can be run within short timeframe		Dhar *et al.* (2021)
Experience	Better motivation	Increases willingness to learn Increase students' interest and enthusiasm in the teaching–learning process	Kharvari and Kaiser (2022); Mazzuco *et al.* (2022); Rodriguez-Abad *et al.* (2021)
	Better understanding	Promote student immersion in the teaching content	Ahmad and Junaini (2020; Ajit *et al.* (2021); Diao and Shih (2019)
	Allows in-depth study	Allows in-depth study of an anatomical structure	Dhar *et al.* (2021)
	Allows more efficient visualization		Parsons and MacCallum (2021)
	Better engagement	Fun Provides enjoyable environment Provides real-time interaction Increases interactivity and physical interactions	Ajit *et al.* (2021); Law and Heintz (2021); Muñoz *et al.* (2022); Quintero *et al.* (2019); Sırakaya and Sırakaya (2022)
	Consolidates laboratory experiments		Diao and Shih (2019)
	Emotional effects		Law and Heintz (2021)
Performance	Improve achievement		Garzón *et al.* (2019)
	Better performance	Enhances proficiency Time efficiency Optimizing surgical times Lower error rate during task execution Enhanced the accurate performance Increased surgical accuracy and precision	Diao and Shih (2019); Ha *et al.* (2021); Innocente *et al.* (2022); Joda *et al.* (2019); Rodriguez-Abad *et al.* (2021); Samad *et al.* (2021)
	Increases concentration		Alzahrani (2020)
	Enhances knowledge retention		Buentello-Montoya *et al.* (2021)
Knowledge transfer	Acquisition of clinical competencies	Enhanced skills through AR training helped to transfer knowledge and skills to clinical settings	Rodriguez-Abad *et al.* (2021); Sheik-Ali *et al.* (2019)
	Improves the teaching of work and employment skills	Provides a unique opportunity to prepare the trainees for complex social situations in a controlled and managed environment	Dhar *et al.* (2021)

(*continued*)

Table 2.
AR-AF model for advantages and/or enablers

Sub-category	Advantages/enablers	Related advantages/enablers	Sample references
Associated with skills acquisition			
Study skills	Acquisition of cognitive skills	Enhances cognitive behavior	Sırakaya and Sırakaya (2022)
	Assists knowledge construction	Enhances physical examination skills, practical skills and clinical skills Helpful for knowledge integration and internalization	Diao and Shih (2019); Quintero *et al.* (2019)
	Creativity		Theodoropoulos and Lepouras (2021)
	Multitasking		Muñoz *et al.* (2022)
Social skills	Enhances communication skills	Better communication and social interaction	Fernández-Batanero *et al.* (2022); Innocente *et al.* (2022)
Self-development skills	Develops positive attitudes		Samad *et al.* (2021)
	Increases self-confidence		Buentello-Montoya *et al.* (2021)
	Enhances soft skills		Law and Heintz (2021)
Associated with organization/environment			
Technology/ hardware	Reduction in the cost		Ha *et al.*, 2021)
	Ease of use.		Mazzuco *et al.* (2022)
	Increase graphic competencies		Diao and Shih (2019)
	Usefulness		Kharvari and Kaiser (2022)
	Easy customization and editing		Martins *et al.* (2021)
Individuals	Enhances the level of satisfaction		Law and Heintz (2021)
	Improved workload		Ha *et al.* (2021); Quintero *et al.* (2019)
	Reduce cognitive load		Sırakaya and Sırakaya (2022) Mazzuco *et al.* (2022)
	Reduces student stress, anxiety		
	Improved guided visit, citizen's feedback	Improves navigation through digital maps	Kharvari and Kaiser (2022); Quintero *et al.* (2019)
Life and safety	AR enhancement the real world	Improves learners' real sense of operation Provides realism to experiences	Mazzuco *et al.* (2022); Rodriguez-Abad *et al.* (2021)
	Increases safety	Decreases risks and radiation exposure for the patient and operating staff Enables safe application of dangerous experiments	Innocente *et al.* (2022); Joda *et al.* (2019; Martins *et al.* (2021)

(*continued*)

Table 2.

Sub-category	Advantages/enablers	Related advantages/enablers	Sample references
Spaces	Distance and remote learning Provided environment facilities for training	Increases information accessibility	Alzahrani (2020); Garzón *et al.* (2019) Martins *et al.* (2021)
	Freedom of experimentation	Informal settings involving activities outside of classrooms	Garzón and Acevedo (2019); Mazzuco *et al.* (2022)

Table 2.

Source: Developed by the authors

RQ2. What challenges and/or barriers have been identified through the existing reviews of augmented reality implementation in education?

This systematic review brings to light several barriers in the integration of AR in education, with a focus on curriculum development and user experience (Table 3). Alzahrani (2020), Diao and Shih (2019) and Sırakaya and Sırakaya (2022) identify the challenge of developing a standardized curriculum for AR education, stemming from the rapid development of AR technology and the varying capabilities of different devices. This challenge is compounded by concerns over AR's compatibility with traditional teaching methods. Educators, as noted by Samad *et al.* (2021), express reservations about the suitability of AR in traditional classrooms because of its complexity and the need for specialized equipment. Experience-related disadvantages for users, such as information overload and difficulties in visualizing abstract information, are highlighted by Garzón and Acevedo (2019), Mazzuco *et al.* (2022) and Theodoropoulos and Lepouras (2021). These disadvantages can lead to reduced engagement with AR technology and potentially impede students' ability to retain information and develop critical thinking skills, as discussed by Law and Heintz (2021) and Martins *et al.* (2021). This review underscores the need for careful consideration and strategic planning in the integration of AR in educational settings to overcome these barriers.

The review identifies crucial concerns regarding the impact of AR on student performance and study skills. Mazzuco *et al.* (2022), Parsons and MacCallum (2021) and Samad *et al.* (2021) observed that AR can serve as a distraction for students, diverting their attention away from the learning objectives. Furthermore, Sırakaya and Sırakaya (2022) suggest that AR might limit students' imagination, while Cannizzaro *et al.* (2022) and Ha *et al.* (2021) found instances of poorer performance in certain applications of AR. A significant issue raised is cognitive overload, which arises when AR requires users to process more data than they are accustomed to, as indicated by Parsons and MacCallum (2021) and Samad *et al.* (2021). This overload can hinder the learning process and lead to a reduction in the effective assimilation of information. Additionally, the review highlights that students who lack the necessary skills to effectively use AR technology may find it challenging to engage with the material, a concern shared by Alzahrani (2020) and Theodoropoulos and Lepouras (2021). The issue of multitasking with AR is also problematic. The reviews of Garzón *et al.* (2019) and Garzón and Acevedo (2019) indicate that multitasking while using AR can lead to lower levels of focus and less effective learning. These findings suggest that while AR has potential benefits in educational settings, its implementation must be carefully managed to avoid these negative impacts on student performance and learning abilities.

Sub-category	Disadvantages/barriers	Related disadvantages/ barriers	Sample references
Associated with usage			
Curriculum	The complexity involved in developing a standardized curriculum		Alzahrani (2020)
	Incompatibility with the usual pedagogical approaches		Alzahrani (2020); Diao and Shih (2019)
	Not suitable for large group teaching		Samad *et al.* (2021)
	Insufficient study time or too much course content		Diao and Shih (2019)
Experience	Information overload		Garzón and Acevedo (2019)
	Difficulty in visualizing abstract applications of probability in mathematics.		Buentello-Montoya *et al.* (2021)
	May increase students' learning difficulty after using AR for a long period of time		Samad *et al.* (2021)
	Difficulty in understanding	Difficulty in understanding 3D vector and 2D visualization Difficulty in understanding geometric shapes	Ahmad and Junaini (2020); Muñoz *et al.* (2022)
	Engagement issues		Martins *et al.* (2021)
Performance	Distracts students (loss of attention)	Difficulty in working simultaneously with AR and concentrating on the lecture	Diao and Shih (2019); Mazzuco *et al.* (2022)
	Reduces imagination		Sırakaya and Sırakaya (2022)
	A poor performance	Tissue movement during surgery poses an obstacle for AR applications, as it can lead to inaccuracies in image alignment The operative time of the surgeon increased	Cannizzaro *et al.* (2022); Ha *et al.* (2021)
Knowledge transfer	No data available		
Associated with skills acquisition			
Study skills	Causes cognitive overload Multitasking		Alzahrani (2020) Garzón *et al.* (2019)
Social skills	No data available		
Self-development skills	No data available		

(*continued*)

Table 3. AR-AF Model for disadvantages and/ or barriers

Sub-category	Disadvantages/barriers	Related disadvantages/ barriers	Sample references
Associated with organization/environment			
Technology/ hardware	Difficult to use		Rodriguez-Abad *et al.* (2021)
	Developing an application with effective functionality	Lack of content developers Difficulty finding free apps	Gasteiger *et al.* (2022); Mazzuco *et al.* (2022); Sırakaya and Sırakaya (2022)
	Internet connectivity	Difficulties with broadband connection and data transfer; perceived lag can cause simulator sickness, poor registration or even missing key animations; network latency can exacerbate these issues	Martins *et al.* (2021); Samad *et al.* (2021)
	Lack of defined and clear technical standards		Muñoz *et al.* (2022)
	Software limitation	AR applications do not allow adding 3D images in application mode Display quality Difficulties regarding the marker readings (distance, environment and movement)	Ajit *et al.* (2021); Diao and Shih (2019); Martins *et al.* (2021); Quintero *et al.* (2019)
	Hardware limitation	Lack of enough features in student devices Characteristics of HMD (e.g. weight, size and display resolution)	Cho *et al.* (2020); Martins *et al.* (2021); Theodoropoulos and Lepouras (2021)
	Cost is expensive	Infrastructure requirements in a large-scale implementation High cost of implementation; high development and maintenance costs; and high investment costs in hardware and software	Gasteiger *et al.* (2022); Joda *et al.* (2019); Muñoz *et al.* (2022)
Individuals	Not aware of AR potential		Buentello-Montoya *et al.* (2021)
	A lack of acceptance	Inadequate teacher ability to use the technology Resistance from teachers	Buentello-Montoya *et al.* (2021); Martins *et al.* (2021); Samad *et al.* (2021)
	Lack of training and knowledge about using AR in education		Alzahrani (2020)
	Low enthusiasm or a low perception of benefits by trainers		Martins *et al.* (2021)

(*continued*)

Table 3.

Sub-category	Disadvantages/barriers	Related disadvantages/ barriers	Sample references
Life and safety	Safety and efficacy issues	Ergonomic problems	Cho *et al.* (2020); Mazzuco *et al.* (2022)
	Not realistic (image alignment because of inaccurate calibration and optical distortions that alter the image) and less animation element		Muñoz *et al.*, 2022)
Spaces	No data available		

Source: Developed by the authors

Table 3.

Advantages/enablers	Sample references	Disadvantages/barriers	Sample references
Enhances learning delivery and can be run within short timeframe	Dhar *et al.* (2021)	Insufficient study time or too much course content	Diao and Shih (2019)
Better engagement	Theodoropoulos and Lepouras (2021)	Engagement issues	Martins *et al.* (2021)
Provides realism to experiences	Mazzuco *et al.* (2022)	Not realistic	Muñoz *et al.* (2022)
Reduction in the cost	Rodriguez-Abad *et al.* (2021)	Cost is expensive	Gasteiger *et al.* (2022)
Easy customization and editing	Martins *et al.* (2021)	AR applications do not allow adding 3D images in application mode	Quintero *et al.* (2019)
		Difficulty finding free apps	Innocente *et al.* (2022)
Ease of use	Kharvari and Kaiser (2022)	Difficult to use	Samad *et al.* (2021)
Reduce cognitive load	Sırakaya and Sırakaya (2022)	Causes cognitive overload	Alzahrani(2020)
Time efficiency	Quintero *et al.* (2019)	The operative time of the technical proficiency increased	Cannizzaro *et al.* (2022)
Optimizing technical proficiency times	Innocente *et al.* (2022)		
Increased technical proficiency	Ha *et al.* (2021)	The learned AR proficiency does not transfer well to the real world	Martins *et al.* (2021)
Increases concentration	Alzahrani (2020)	Distracts students (loss of attention)	Diao and Shih (2019)

Source: Developed by the authors

Table 4.
Duality of reported factors

The final set of disadvantages identified in the review pertains to technological, individual and environmental aspects of AR in education. Buentello-Montoya *et al.* (2021) and Rodriguez-Abad *et al.* (2021) highlight significant technological and hardware issues, including difficulties with the user interface. Network connectivity problems are noted by Martins *et al.* (2021) and Sırakaya and Sırakaya (2022), while the high cost of implementation and maintenance is a concern raised by Ajit *et al.* (2021), Dhar *et al.* (2021), Joda *et al.* (2019) and Law and Heintz (2021). At the individual level, a lack of awareness and acceptance of AR in education is identified, primarily because of inadequate teacher training or resistance from educators, as discussed by Gasteiger *et al.* (2022) and Theodoropoulos and Lepouras (2021). Additionally, the implementation of AR in education raises safety concerns, including excessive study time, ergonomic issues such as discomfort and eye strain and efficacy risks in specific applications such as health-care education. These concerns are highlighted in the studies by Alzahrani (2020), Cho *et al.* (2020), Mazzuco *et al.* (2022) and Rodriguez-Abad *et al.* (2021). These disadvantages underscore the need for a balanced and well-considered approach to integrating AR into educational environments.

RQ3. Do the reported barriers/enablers differ across educational domains?

Duality factors. The concept of duality in the context of AR's advantages/enablers and disadvantages/barriers is a recognition of the dualistic nature of these factors in educational domains (Table 4). This duality means that certain aspects of AR technology can act as facilitators in some scenarios while posing challenges in others. This phenomenon is largely attributable to the differing requirements and characteristics inherent to each educational domain. For instance, in the health domain, Ha *et al.* (2021) and Sheik-Ali *et al.* (2019) highlight that AR can significantly enhance surgical accuracy and precision. However, Cannizzaro *et al.* (2022) point out a contrasting issue where the movement of tissue during surgery can increase intraoperative error in image alignment, demonstrating the dual nature of AR in this field. On the other hand, in the STEM domain, AR's duality is also evident. Sırakaya and Sırakaya (2022) observe that AR can be used effectively to engage students and reduce cognitive load, enhancing the learning experience. However, this benefit is counterbalanced by findings from Theodoropoulos and Lepouras (2021) and Alzahrani (2020), who note that AR can be difficult to use, potentially leading to cognitive overload. This illustrates how the same technology that simplifies and enhances learning in one aspect can, under different circumstances or without proper implementation, lead to increased complexity and hinder learning.

In the context of AR's advantages and disadvantages, the quality of AR content is a critical factor that contributes to its dual nature. High-quality AR content is essential for creating realistic and immersive experiences, which can significantly enhance the effectiveness of AR as an educational tool and promote student engagement. Dhar *et al.* (2021) and Parsons and MacCallum (2021) emphasize that when AR content is of high quality, it can greatly enrich the learning experience by providing lifelike simulations and interactive environments that capture students' interest and facilitate deeper learning. On the other hand, the quality of AR content can also have negative implications when it is poor. Diao and Shih (2019) and Samad *et al.* (2021) note that low-quality AR content can lead to distractions and a loss of student attention, undermining the educational process. Similarly, Martins *et al.* (2021) observe that poor-quality content can result in a lack of student engagement, diminishing the potential benefits of AR in learning and teaching.

The compatibility and quality of devices are indeed pivotal factors in determining the efficacy of AR applications in educational contexts. Law and Heintz (2021) point out that AR applications requiring high-resolution displays necessitate the use of high-performance devices. However, this requirement introduces a significant barrier, as Gasteiger *et al.* (2022) and Muñoz *et al.* (2022) observe that such devices can be expensive or inaccessible for some students, which may impede equitable access to AR-enhanced education. This disparity in device accessibility can have a direct impact on student engagement and concentration. Alzahrani (2020) and Theodoropoulos and Lepouras (2021) highlight that when students do not have access to the necessary quality of devices, it can limit their ability to fully engage with the AR content, thereby reducing the overall effectiveness of the learning experience.

Finally, AR can deliver optimized technical skill proficiency (Ha *et al.*, 2021), but its use may not always lead to time efficiency. For instance, AR can lead to reduced surgical time and improved patient outcomes (Sheik-Ali *et al.*, 2019). However, if the goal of using AR is to improve time efficiency, the results may not always be positive. For example, Ha *et al.* (2021) and Cannizzaro *et al.* (2022) found that the use of AR sometimes increases the surgeon's operative time, which could be counterproductive in situations where time is a critical factor. Furthermore, the operation of AR applications may require a certain degree of technical expertise to handle software and hardware effectively, potentially increasing the time required for training and setup (Theodoropoulos and Lepouras, 2021).

As mentioned above, the duality of advantages/enablers and disadvantages/barriers across educational domains is a complex issue that can be attributed to several factors. While each education domain has its requirements, the quality of the content, devices used and purpose of using AR can also contribute to duality. To fully realize the potential of AR in education, it is essential to understand these factors and tailor its use accordingly.

Discussion and conclusion

This systematic review identifies the barriers and enablers of AR adoption in education across different domains and contexts using the AR-AF-model. The results reveal that the advantages and disadvantages of using AR in education are subject to duality and are influenced by various factors that impact its adoption and implementation. In this discussion, we consider how the results align with the CFIR framework, and what implications and recommendations can be derived from them. We also consider in more depth the factors that cause duality, highlighting their influence on the integration and use of AR in education. We also note how each factor has both direct and indirect impacts on multiple aspects of AR application in education, creating a nuanced and interconnected system of influence.

Intervention characteristics

The intervention characteristics domain refers to the features of AR as an educational tool that affect its implementation. This review identified several advantages and disadvantages of AR in education, which can be mapped to the CFIR constructs of the intervention characteristics domain. For example, Ahmad and Junaini (2020), Buentello-Montoya *et al.* (2021), Muñoz *et al.* (2022) and Quintero *et al.* (2019) demonstrated that AR possesses significant pedagogical benefits, offering a relative advantage over traditional methods within the educational domain. Further supporting this, Alzahrani (2020), Law and Heintz (2021) and Sırakaya and Sırakaya (2022) found notable improvements in student engagement because of AR implementation. Additionally, Ajit *et al.* (2021), Garzón *et al.* (2019) and Rodriguez-Abad *et al.* (2021) identified enhancements in learning outcomes attributable to AR. Conversely, challenges such as high costs, as identified by Dhar *et al.* (2021), Gasteiger *et al.* (2022) and Joda *et al.* (2019), along with complexity issues as noted by Mazzuco *et al.* (2022) and Samad *et al.* (2021), pose significant barriers. Technical difficulties, highlighted in review of Cho *et al.* (2020), Diao and Shih (2019) and Martins *et al.* (2021), along with resource scarcity as reported by Innocente *et al.* (2022) and Sırakaya and Sırakaya (2022), also impede the adoption and diffusion of AR in educational settings. These factors significantly influence the perceptions and attitudes of potential users and stakeholders, underscoring the necessity to address these barriers while leveraging enablers in the design, development and evaluation of AR applications for educational purposes.

Outer setting

The external environment or context, termed the outer setting domain, plays a crucial role in the implementation of AR in education. Alzahrani (2020), Kharvari and Kaiser (2022) and Law and Heintz (2021) have found that AR is adept at meeting the diverse needs and preferences of learners across various domains and cultures. This is primarily because AR can offer personalized, interactive and immersive learning experiences, as evidenced by studies from Ahmad and Junaini (2020), Ajit *et al.* (2021), Dhar *et al.* (2021), Diao and Shih (2019) and Gasteiger *et al.* (2022). However, the implementation of AR is contingent on the availability and accessibility of essential resources. This includes devices (Cho *et al.*, 2020; Innocente *et al.*, 2022; Theodoropoulos and Lepouras, 2021), reliable internet connections (Sırakaya and Sırakaya, 2022), quality content (Rodriguez-Abad *et al.*, 2021) and adequate support (Alzahrani, 2020; Fernández-Batanero *et al.*, 2022). Additionally, the adoption of AR in educational settings is influenced by social norms and expectations from various stakeholders, including teachers, parents, administrators and policymakers, as indicated by Law and Heintz (2021). These social factors can either create opportunities or pose challenges for the acceptance and support of AR interventions in education. Given these findings, it is evident that the outer setting is a critical factor in the successful implementation of AR in educational contexts. It underscores the importance of considering these external factors and engaging relevant stakeholders and partners throughout the process of AR implementation in education.

Inner setting

The inner setting domain refers to the organizational features that affect the implementation of AR in education. Several factors related to the inner setting emerged, such as structural characteristics, networks and communications, culture, implementation climate, readiness for implementation and leadership engagement. Ajit *et al.* (2021) highlighted that the size of educational institutions can significantly influence the adoption of AR, affecting available resources and capacities. Additionally, Garzón and Acevedo (2019) noted that the type of institution plays a role, while Diao and Shih (2019) emphasized the importance of institutional structure in determining the flexibility for integrating AR interventions, as supported by Fernández-Batanero *et al.* (2022). AR's influence on communication and collaboration is also notable. Dhar *et al.* (2021) and Innocente *et al.* (2022) found that AR could either facilitate or impede interactions between teachers and students, creating new modes of feedback and interaction. The alignment or conflict of AR with the values and beliefs of educators and learners is another critical aspect. Reviews of Garzón and Acevedo (2019) and Samad *et al.* (2021) showed that AR could either challenge or reinforce existing pedagogical practices. In terms of creating a climate for change, Cho *et al.* (2020) and Parsons and MacCallum (2021) observed that AR could generate a supportive or resistant environment for innovation, influencing aspects such as priority, tension for change, compatibility and goal setting. Lastly, the role of leadership in AR implementation is vital. Kharvari and Kaiser (2022) and Sheik-Ali *et al.* (2019) identified that leadership engagement, resource availability, access to information and presence of champions can greatly enhance or reduce the motivation and commitment toward AR implementation. These findings suggest that organizational readiness and the culture for implementing AR in education are significantly influenced by various factors within the inner setting. It is, therefore, imperative to consider and address these organizational barriers and facilitators when implementing AR in educational contexts.

Characteristics of individuals

The characteristics of individuals domain refers to the factors that influence the implementation of AR in education by individuals involved in it. The review analyzed several characteristics of individuals, such as knowledge and beliefs about the intervention, self-efficacy, individual stage of change, individual identification with the organization and other personal attributes. Buentello-Montoya *et al.* (2021) identified the level of awareness among educators and learners as a key determinant in the acceptance and adoption of AR. Fernández-Batanero *et al.* (2022) emphasized the role of understanding in this context. Attitudes toward AR, as studied by

Gasteiger *et al.* (2022) and Samad *et al.* (2021), also critically affect its adoption. Perceptions about AR's benefits and challenges, highlighted in the work of Martins *et al.* (2021) and Alzahrani (2020), are influential in shaping acceptance. The confidence and competence of users in using AR technology, as studied by Ahmad and Junaini (2020), Innocente *et al.* (2022) and Muñoz *et al.* (2022), directly impact performance and satisfaction with AR interventions. This aspect was further explored by Cannizzaro *et al.* (2022) and Rodriguez-Abad *et al.* (2021). Individual readiness and willingness to adopt and use AR, as discussed by Alzahrani (2020) and Kharvari and Kaiser (2022), influence engagement and participation in AR interventions, an aspect further examined by Law and Heintz (2021). The sense of belonging and identity with educational institutions, highlighted by Ajit *et al.* (2021) and Fernández-Batanero *et al.* (2022), also plays a significant role in determining loyalty and commitment to AR interventions. Finally, personal factors such as age, gender, culture, learning style and motivation, as identified in studies by Cannizzaro *et al.* (2022) and Law and Heintz (2021), among others, shape preferences and needs for AR interventions. These factors can either facilitate or impede AR adoption in education, underscoring the necessity to tailor and adapt AR interventions to suit the individual differences and needs of users.

Process

Implementation planning is crucial for achieving successful adoption of AR in education, as indicated by several studies, such as those conducted by Buentello-Montoya *et al.* (2021), Gasteiger *et al.* (2022), Sırakaya and Sırakaya (2022) and Theodoropoulos and Lepouras (2021). These studies suggest that the absence of a well-defined implementation plan can lead to significant obstacles in the adoption process, a viewpoint shared by Fernández-Batanero *et al.* (2022). The planning process, as outlined by Diao and Shih (2019), Law and Heintz (2021), Mazzuco *et al.* (2022) and Quintero *et al.* (2019), should encompass several critical steps. These include defining clear goals and objectives, allocating appropriate resources and budgets, assessing needs and identifying gaps, developing a comprehensive project plan, engaging key stakeholders and establishing a guiding vision for the implementation. Ongoing support, both before and after the initial launch phase, is vital for the sustainability of AR in educational settings, as highlighted by Alzahrani (2020) and Martins *et al.* (2021). This support ensures that the implementation is not just a one-off event but a continuous process of improvement and adaptation. In addition, involving key stakeholders such as teachers, students, parents and policymakers in the design of AR applications is crucial, according to Fernández-Batanero *et al.* (2022), Law and Heintz (2021) and Samad *et al.* (2021). Their involvement can foster a sense of ownership and enhance buy-in, which is essential for the successful integration of AR in educational practices. Finally, evaluation is another critical component, necessary for assessing the benefits of the system and securing ongoing funding, as pointed out by Gasteiger *et al.* (2022). While most reviews, including those by Joda *et al.* (2019), Quintero *et al.* (2019) and Sırakaya and Sırakaya (2022), report on the effects of AR applications, they often lack data on the long-term impact of these applications, highlighting a gap in the current research and underscoring the need for longitudinal studies in this area.

Factors causing duality

In conclusion, understanding the duality factors surrounding the advantages and disadvantages of using AR in education (Table 5) is crucial for its successful integration, which requires educators and developers to navigate several challenges. These include aligning educational goals with AR applications, adapting to different educational domains, selecting the appropriate direction for AR integration and considering the age and technological experience of students. By acknowledging and addressing these factors, educators can optimize

Table 5.
Main factors cause duality

Factor	Description of enabler	Sample reference	Description of barrier	Sample reference
Purpose or goals of AR	AR can serve different pedagogical purposes depending on the learning objectives, content, learners and environment	Garzón *et al.* (2019)	Finding or developing AR applications that match the educational goals and learning objective is a major challenge	Mazzuco *et al.* (2022)
Education domain	Different domains require different levels of interactivity, realism, collaboration, authenticity or personalization from the AR applications	Dhar *et al.* (2021)	Creating a customized AR application requires technical skills and resources many educators do not have	Rodriguez-Abad *et al.* (2021)
The way of integration AR into curriculum	The direction or manner of integrating AR into curriculum and pedagogy influences the design, cost, realism and engagement	Gasteiger *et al.* (2022)	Choosing an appropriate direction of AR is challenging because of design complexity, cost, realism and engagement issues	Ahmad and Junaini (2020)
Student age and experience	AR lessons should cater to the specific age group, considering their cognitive and motor abilities, prior knowledge and motivation	Theodoropoulos and Lepouras (2021)	Younger students may struggle to comprehend and use AR, while older students' preconceived notions may impede their learning	Alzahrani (2020)

Source: Developed by the authors

the potential benefits of AR while mitigating its potential drawbacks, ultimately unlocking the full potential of AR in education. The complex relationships among these factors and their impact on AR integration and use in education highlight the intricate nature of this area. These direct and indirect effects create a cascade of implications that significantly influences the success of AR implementation within an educational context.

This study has certain limitations that potentially impact the comprehensive understanding and interpretation of the findings. Its exclusive focus on reviews published in English from 2017 to 2022 may have inadvertently excluded pertinent studies in other languages or from earlier periods that remained relevant to the topic. Furthermore, the study's concentration on AR technology may have led to overlooking insights from related technologies, such as VR, MR or XR. The absence of a meta-analysis further undermines the validity and reliability of the study's conclusions. Hence, these limitations need to be acknowledged to understand the scope and applicability of the findings of this study.

Understanding these implications can assist educators and policymakers in devising context-sensitive strategies to maximize the benefits and minimize the potential drawbacks of AR use in education. Moreover, future research should further explore these relationships and impacts with the aim of providing practical guidelines for the successful integration of AR in various educational domains.

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Supplementary material

The supplementary material for this article can be found online.

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