

Review

Augmented Reality: A Systematic Review of Its Benefits and Challenges in E-learning Contexts

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Abstract: Augmented reality (AR) has received increasing attention in the research literature as a fundamental pedagogical tool that can enhance learning at most educational levels. In academic contexts, this technology permits the superimposing of three-dimensional images onto the real environment. Although AR has been found to enhance learning in the academic environment, no systematic review of it has been conducted to identify, evaluate, and summarize empirical findings on its advantages and challenges in e-learning contexts. Hence, a systematic review of the research literature was conducted on the use of AR in e-learning contexts, with a focus on the key benefits and challenges related to its adoption and implementation. Electronic searches on databases, including Springer, Science Direct, EBSCO, and Google Scholar, were performed to retrieve relevant journal articles; 28 studies were included after they were screened using the inclusion and exclusion criteria. The key benefits of using AR in e-learning included support of kinesthetic (tactile) learning, collaborative learning, distance/remote learning, learner-centered learning, and creative learning. Studies also reported that AR enhanced students' engagement, motivation, attention/focus, interactivity, verbal participation, concentration, knowledge retention, and spatial abilities, as well as information accessibility. The findings suggest that challenges associated with AR in e-learning include information and cognitive overload, lack of experience in using the technology, resistance from teachers, complex technology, costly technology, and technical issues, such as connectivity problems.

Keywords: augmented reality; adaptive learning; collaborative learning; E-learning; mobile learning; gamification; kinesthetic learning; real-world simulations; robotics; virtual reality

1. Introduction

1.1. Background

Over the past decade, the field of augmented reality (AR) has been established as one of the most promising areas of computer graphics. During this time, myriad groundbreaking applications have been actualized, increasing the significance of AR in daily life [1]. Such developments have not remained outside the academic realm; rather, they have had a significant influence on this sector through the creation of new disseminating tools, knowledge, and learning structures [2]. Refs. [3,4] noted that novel lines of actions and ideas that have been implemented are linked to various forms of established technologies, such as electronic learning (e-learning), ubiquitous learning (u-learning), mobile learning (m-learning), and game-based learning. Ref. [5] proposed that such technological innovations in academic setting allow various fields of knowledge to collaborate to generate different academic issues and complementary methods, content, and learning objectives.

Indeed, [6] postulated that AR embeddedness in the field of education generates positive learning and teaching outcomes. Ref. [7] proposed that the use of AR in education provides portable, low-cost, stress-free, and promising solutions for use in a variety of academic settings. However, the challenges

associated with its implementation have also been reported by academic researchers [8,9]. Ref. [8] identified the challenges of usability and inadequate experience with the involved technologies, and [9] noted several issues related to resistance from teachers, information overload, and usability. Although advantages and disadvantages of AR have been identified in the literature, no systematic reviews of this topic in the current literature have been conducted, which has created a knowledge gap, necessitating further exploration in this area.

1.2. Purpose

This systematic review was intended to probe deeper into the applicability and pertinence of AR in e-learning contexts, revealing its benefits and challenges, as reported in the published research. The purpose of this review was to inform academicians of the advantages and challenges of using AR, as reported in the published research. It was projected that the findings reported in this systematic review would help find answers to questions about the applicability of this technology in the e-learning context, share policies (i.e., the relationship between AR pedagogy and academic outcomes for policy makers), and improve practice (for practitioners). The analysis of the challenges of AR in this context was expected to uncover trends, limitations, and affordances, thereby creating opportunities for further research and a general vision of the future.

1.3. Objectives

The key objectives of this review were to, first, highlight the advantages/benefits of using AR in e-learning contexts, and second, identify the challenges of adopting and applying AR in the educational setting. As part of these objectives, the distribution of published studies over time on the use of AR in academic settings was examined using the Web of Science databases. The goals of this study were to provide recommendations for both AR development and education and suggest future directions for future studies.

1.4. Research Questions

This investigation explored two research questions: (i) what are the advantages of AR in academic settings, as reported in the research literature? (ii) what are the challenges of AR in academic settings, as reported in the research literature?

2. Augmented Reality

2.1. Definition and Taxonomy

Ref. [10] defined AR as a technology that overlays virtual objects (augmented constituents) onto the real world. The Oxford Dictionary defines this as a technology that superimposes a computer-produced portrayal on a user's outlook of the real world and, therefore, shows a composite perspective. In their handbook of AR, [11] hypothesize that AR is a real-time direct or indirect outlook on a real-world physical environment, which is improved (augmented) by adding virtual computer-generated information to it. This definition is congruent with that of Silva, Oliveira, and Giraldi [12], who view AR as a concept used for computer-generated 3D environments, which allow the user to cross the threshold and interact with synthetic environments. In other words, the individual using the computer is able to "immerse" him/herself to varying degrees into the computer's synthetic virtual world that may be either a simulation of some form of reality or a simulation of a complex phenomenon.

According to [13], AR can be viewed as a computerized extension of people's reality in a system that is characterized by three key features: combined reality and virtuality, interactive in real time, and presented in 3D. As noted by [11], AR is within the context of reality and virtuality, which Fumio Kishino and Paul Milgram described as a continuum spanning real and virtual environments. In this context, AR and augmented virtuality (AV) arise, where AR represents the real world and AV represents the virtual world. For this reason, [14] consider AR to be a concept in technology rather than a certain

form of technology. Similarly, [6] posited that AR should not be limited to any particular type of technology but viewed as a broad concept that can be conceptualized beyond technology. Thus, AR should play a supplementary role in any setting rather than replace reality in such settings. For instance, in academic settings, virtual objects can be incorporated into the real world, and AR implementation could exploit the affordances of that real world by offering supplementary and contextual information that enhances (augments) students' experiences of reality [15].

2.2. Application of AR in E-Learning

Vast transformations are currently taking place in learning practices and paradigms. Presently, the continued rise of the internet and related technologies has led to the introduction of new pedagogical approaches based on the sensation of time and space in the use of knowledge. In the realm of e-learning, shrewd instructors are looking for an appropriate mix of innovative teaching technologies and methodologies to enhance the efficacy of instruction. AR was developed for this reason. This innovative technology has allowed e-learning learners to receive instruction using a mixture of the virtual and real world in varying proportions to achieve a degree of immersion that no virtual equipment can provide [16]. It is a novel medium that combines various elements from social computing to tangible and ubiquitous computing. Given its capabilities, [4] argues that AR (especially game-based AR) brings to the e-learning segment the unique affordances and benefits of adaptive learning, including enhancement of student motivation, engagement, involvement, and comprehension.

Given the evolution of AR, other related technologies, and technological concepts, [17] have identified the need for e-learning platforms to shift from simplistic and monolithic frameworks dealing with the fundamentals of course management, design, and delivery, to more "flexible" paradigms involving active learners and the use of external stimuli that augment their motivation. With innovative technologies, such as virtual reality (VR) and AR, e-learning institutions now have a robust and flexible learning environment that serves learners with improved dynamicity and personalization [17]. This convenience is underscored by the ability of innovations, such as VR and AR to present information by orchestrating a number of functionalities that are grounded on service-oriented architectures. For example, [18] emphasize that AR is vital to e-learning because it encourages kinesthetic and 3D perspectives. As demonstrated subsequently, such advantages allow students who are e-learners that struggle with the visualization of phenomena to envisage such phenomena in the real world, even in extreme complex scenarios. As pointed out by [19], and importantly for this review, AR in e-learning contexts entails combining digital information within an existing environment (physical, real-world settings), where the elements are augmented or supplemented through computer-generated sensory inputs that may include video, sound, GPS data, graphics, and visualizations.

2.3. The Role of Robotics in AR-Based Learning

As the field of robotics continues to grow tremendously, scholars have attempted to explore how robotics technology can combine with a number of other innovative technologies to improve usability and operational efficiency. In this study, [20] explored the use of robotics in the education of primary-school-age learners, aiming to shed light on planning applications about robotics in Turkey. The researchers also aimed to help these learners get close to robotics and AR technology. In this context, their exploration was supported by the AR robotics construction programming for both fourth and fifth-grade learners. The findings of this study demonstrate that robotics in AR-based learning can improve learning outcome, but it is vital to identify different application methods to enhance learners' motivation and enable the use of robotics that fits their creative skills. The scholars also suggest that there is a need for teacher training to enable the effective combination of AR with robotics. The researchers point out further exploration is necessitated, especially starting from elementary schools to students at the university level.

Correspondingly, [21] consider robotics as a flexible medium for learning, offering opportunities for design and construction, particularly with limited time and funds. According to the researchers, the new versions of education robotics technologies allow learners to control the behavior of tangible models by means of other technologies such as VR and AR. This enables the possibility of new forms of science experiments, where learners, even in kindergarten, can investigate everyday phenomena [21]. Ref. [22] make a similar observation in their study involving 300 students in secondary school. In this study, the researchers explore the effectiveness of Vollstedt, a LEGO Robotics Learning program for high school students. Their findings suggest that, when utilizing this application in an AR learning environment, the interest of the students and knowledge of mathematics, engineering, technology, and science increased considerably. Similarly, [23] created a robotics education application called FASTBOT to allow students to make better decisions regarding their future careers. The tool allows students to program, find solutions to given tasks, and apply their knowledge in combination with programming. The results suggest that that the robotics systems can allow students to become more aware of their capabilities, enable effective problem solving, and enhance effectiveness in working towards the desired results in their robotic interactions. In addition, this research suggests that robotics applications such as FASTBOT can be effective in enabling students to understand better different aspects of mathematics, technology, and science.

Based on the overview of these studies, it is apparent that both AR and robotics can benefit each other in terms of increasing usability and operational efficiency. Most of the studies presented here highlight the key roles and contributions of robotics in an AR-based education system. There are others, however, that explore and document the application of AR in robotics, where AR acts as a new medium for interaction and information exchange with the capability to enhance the effectiveness of the human–robot interaction (HRI) [24]. The combination of robotics and AR can allow students to learn complicated academic aspects, especially in sciences such as biology, mathematics, and chemistry, and is particularly useful in medical procedures [25,26]. When applied to the field of education, robotics can change the way learners learn and, in turn, create a more motivated, knowledgeable, and well-adjusted student. Further, in the face of teacher shortage, educators and their institutions are turning to AR-powered robotics to provide instruction and educational support. This is especially fundamental in teaching students with disabilities, an area that is seen to have a personnel shortage. As reported by [27], when provided with the capabilities of human intelligence, robots, as well as other assertive devices, have the potential to empower people with disabilities with instruction and academic support. Some of these capabilities, especially for students with disabilities, may include context awareness, scalability, tirelessness, precision, and embodiment, making robotics particularly beneficial in instruction roles.

3. Methods

3.1. Selection of Articles

A systematic search was performed to identify all literature pertaining to the benefits and advantages of using AR in education, and particularly, in e-learning contexts. To guide this research, a brief scoping review and evaluation of key research on AR in various sectors were conducted to identify common terminology and implement a more in-depth search. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) recommendations were adhered to, as described by [28]. The primary search strategy included electronic searches in four major databases, including Springer, Science Direct, EBSCO, and Google Scholar. This review included only studies published from 2009 through 2019. This inclusion timeframe was selected to reflect the most recent, accurate, and extensive (long-standing) evidence-based peer-reviewed studies. Furthermore, as the demand for AR in education and other sectors has increased during the last decade [29], this period marks a crucial time to evaluate how the technology has been beneficial and the challenges that have been encountered by those who have adopted and implemented it at various levels of education.

3.2. Identification of Articles

The researcher used the advanced search function and entered the search terms “augmented reality” and “augmenting reality” because scholars in the field tend to use these terms interchangeably. The researcher in this review used both keywords with the Boolean operator “OR” to combine multiple search terms in order to obtain relevant results relating to AR in e-learning contexts. Although VR and mixed reality (MR) are components of AR, the researcher did not search for articles specifically addressing VR or MR in academic settings in order to narrow the scope to address only AR. Although these concepts are related, they accomplish different goals in different ways, as noted by [30] and therefore, their applicability in academic settings varies greatly. Extensive phrases, including “benefits of augmented reality in e-learning/education/online learning/virtual learning/mobile learning,” were also used to identify key studies. Alternatives to benefits and challenges in relation to AR in e-learning/education included terms, such as “pros” and “cons” and “advantages” and “disadvantages.” The abstracts and titles of all the retrieved articles were independently reviewed for relevance. If deemed relevant and eligible, the full text was retrieved for a full review. Each eligible article’s reference list was also reviewed for other articles with similar themes to improve the results of the search. The eligible papers from these searches were then read and screened using the inclusion and exclusion criteria established for this systematic review, as illustrated in Table 1.

Table 1. Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
Addressed AR in an academic setting	Addressed related concepts (e.g., VR and MR)
Published from 2009 through 2019	Published before 2009
Written in English	Non-English publication
Peer-reviewed journal	Not a peer-reviewed journal
Published study	Unpublished study (e.g., proposal and ongoing project)
Original publication	Duplicate

3.3. Inclusion and Exclusion Criteria

This study’s inclusion and exclusion criteria set the boundaries and scope for the scholarly publications that were included in the final review. These criteria were determined after the establishment and refinement of the research topic and the objectives. A variety of factors were considered in formulating the eligibility criteria to define a practical scope of analysis, enhance the study’s focus, and ensure the inclusion of only recent articles. First, the researcher included only articles that addressed AR in academic contexts (formal education), where outcomes could be measured. Other related technologies, such as VR and MR, which address similar benefits, limitations, and challenges in academic settings, were not included in order to narrow the scope of the review and enhance the focus of the analysis. Similarly, articles published before 2009 were excluded from this study to allow a review of studies published in the past decade (i.e., from 2009 through 2019). This allowed studies to be included that could be considered recent, thereby reporting various fundamental advancements in technology. Only peer-reviewed published studies were included in this review because they were judged to have more credibility than studies that were not reviewed or published. Only articles published in English were considered for inclusion. Although there are software programs that can translate articles to English, the researcher was skeptical about the quality and outcomes of the translation, which informed the decision to exclude non-English articles. Only original articles, not duplicates, were included in this study. To determine the originality of a publication, the researcher investigated the authors, publication dates, and journals where the studies were published. For instance, Google Scholar provided the results for most of the duplicates in this study. Using the search criteria that included the author, publication date, and journal, the researcher was able to identify original works. For example, [31] had an exact duplicate published by [32],

which was retrieved from Google Scholar. After examination, the researcher determined that the study was originally published by [31].

3.4. Data Coding, Analysis, and Appraisal

As noted previously, the researcher read through all the selected articles that met the inclusion criteria, and using content analysis, identified the patterns in relation to the benefits and challenges of using AR in e-learning contexts. The research objectives and questions were used to extract relevant data from the reviewed articles. The Critical Appraisal Skills Program (CASP) for qualitative and quantitative research was used to crosscheck the extracted and coded data and evaluate the studies (CASP, 2018). This tool is considered valid for conducting critical appraisals of research studies in a wide variety of settings.

3.5. Data Extraction and Synthesis

3.5.1. Data Gathering

The data were extracted using carefully designed forms (Microsoft Word tables) and undertaken with the appropriate synthesis in mind. Microsoft Word, an application by an American multinational technology, as chosen because it allowed the researcher to create tables for the easy extraction and synthesis of the data. To chart the data from the extracted studies, the researcher created a descriptive summary of the results that addressed the objectives and research questions previously stated in the introductory section of this review. A draft of the charting template was developed to allow efficient data coding. The charting form was left open to allow editing and additional unforeseen data during the analysis, which allowed the process to be iterative. The key items on the charting form included the author, year of publication, learner type, AR technology, advantages, challenges, and key inference.

3.5.2. Data Synthesis

A thematic analysis protocol was used in the synthesis of data recorded on the charting form after data gathering/extraction. Thematic synthesis, as described by [33], provides a range of established techniques and methods for the identification and development of analytical themes for the purpose of secondary data synthesis. This method was adopted in this review for three reasons. First, the process of synthesis provides great transparency and the outcomes are easily accessible [33]. Second, thematic synthesis is also used for the synthesis of both quantitative and qualitative data. Third, this method was suited to the objectives of the present study, as it aimed to aggregate evidence and highlight patterns within the data. This process was conducted in three stages, with all steps applied to all studies, including both qualitative and quantitative analyses. The first stage involved coding (identification of text or other data items), as described on the charting form. Each article that was identified after the inclusion and exclusion criteria was read twice to ensure that every item was coded. The second phase involved analyzing the similarities between the codes related to the benefits and challenges of using AR in education, and these were categorized as “descriptive themes” and “descriptive patterns” across the included studies. These descriptive patterns and themes are presented subsequently to facilitate comparisons within and between studies for reporting and discussion. The final step involved the establishment of analytic themes to allow the researcher to synthesize the findings across studies and interpret their meanings. Doing this allowed the researcher to group the studies that reported the benefits of AR in education and those that highlighted the challenges of its application.

4. Results

4.1. Search Results

As described in the methodology section, articles for this systematic review were retrieved from the Springer, Science Direct, EBSCO, and Google Scholar databases, which are used extensively

to retrieve accurate and suitable scholarly data from published qualitative and quantitative studies. These databases were selected because they complied with the protocol requirements and protocol-specific parameters reported in a variety of academic studies. The searches revealed 303 articles from the databases, of which 44 were duplicates, thereby reducing the number of articles to 259. After reviewing their titles and abstracts, 221 articles were excluded because they did not meet the inclusion criteria regarding publication date, language, or focus of the study, and 10 additional studies were excluded after their full-text reviews for eligibility. The findings reported in those studies did not satisfy the objectives of this study in terms of reporting the benefits and challenges of AR in e-learning, leaving 28 articles available for the analysis, see Figure 1. The researcher proceeded to identify the key benefits and challenges of using AR in e-learning contexts using the 28 articles selected for inclusion in this systematic review. The findings are reported in the ensuing individual sections, and recommendations are provided subsequently.

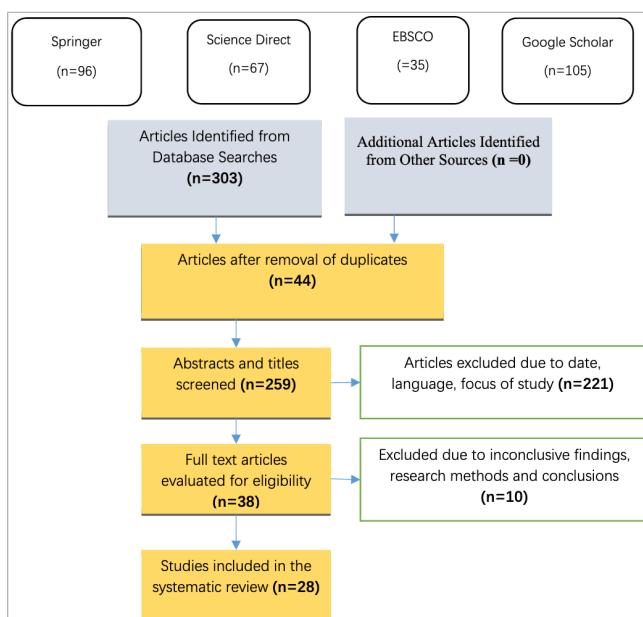


Figure 1. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram.

Results of the Thematic Analysis

The results of the thematic analysis indicated that the application of AR in academic settings had a variety of benefits and challenges, see Table 2. AR was found to promote kinesthetic (tactile) learning, enhance interactivity, facilitate students' engagement and participation, improve satisfaction with learning and outcomes, and encourage collaborative learning, among other benefits. The major challenges, as reported in these studies, may be categorized into pedagogical, learning, and technological issues. Pedagogical issues encompassed resistance from teachers and their lack of skills, training, and experience in the use of AR technologies. Learning issues, based on the findings, included cognitive overload and health issues. Technical issues included connectivity issues and cumbersome devices.

Table 2. Summary of the key findings from the included studies.

Author/Date	Research Design	Participants	Students' Educational Level	Benefits	Challenges	Inferences
Chien et al. (2010)	Randomized controlled study; experimental	30 medical students	Tertiary; Higher learning	Three-dimensional visualizations, and kinesthetic learning; provides student with an interactive environment; promotes students' interest and knowledge retention; students learn faster and more effectively; helps with memorization	None noted	AR can be helpful to students learning anatomy in a higher education setting because it has several benefits compared to traditional systems, including 3D visualization and improvement in students' motivation and knowledge retention.
Santos and Corbi (2019)	Randomized controlled study; experimental	30 high school students (63% boys and 37% girls)	High school	Kinesthetic learning; 3D visualizations; enables collaborative learning; improves students' motivation and knowledge retention	None noted	The study suggests that the fundamental benefit of AR is that it allows kinesthetic learning, which promotes both collaborative and individualized learning.
callIqbal et al. (2019)	Exploratory study	No participants	Tertiary; Higher education	Promotes kinesthetic learning; provides prompt feedback; enhances students' motivation and engagement; promotes better interactions and adaptability	None noted	This study suggests that AR promotes kinesthetic learning and prompts feedback. The technology facilitates motivation and students' engagement. The authors note that AR promotes better interactions and adaptability.
Quintero et al. (2015)	Experimental; app development	Engineering students from a Calculus I course	Tertiary; Higher education	Fosters mathematical and cognitive skills; promotes spatial visualization skills; promotes efficient and effective learning	None noted	This study concluded that the key advantage of using AR in learning is that it promotes mathematical and cognitive skills.
Virata and Castro (2019)	Plan-Do-Study-Act or PDSA	High school learners from an exclusive academic institution for girls in Manila	High school	Improvement in the appreciation of subject areas, such as chemistry; improved learning outcomes; easy to use; improved motivation and learning satisfaction	Teachers may have difficulty using the technology; teachers might not find compatible apps that will meet their pedagogical needs; oversimplification of visualization by the technology	This study indicates that AR provides various affordances in a school setting, including improvements in the learner's motivation and engagement, enhancement of learning satisfaction, and improvements in overall academic outcomes. However, the challenges are the use of the technology by teachers and the lack of applications that are compatible with learning and teaching objectives.

Table 2. Cont.

Author/Date	Research Design	Participants	Students' Educational Level	Benefits	Challenges	Inferences
Singhal et al. (2012)	Experimental; app development	No participants	High school	AR allows tangible interactions with learning materials; improves students' engagement and participation in learning; has simplicity and ease of use for both the students and teachers	None noted	The researcher developed a technology using AR for a program to teach high school students chemistry. The researchers claim that such applications allow tangible interactions in the learning process; this also improves learning engagement and participation.
Kesim and Ozarslan (2012)	Exploratory, qualitative study	No participants	All levels	Allows smooth transition between reality and virtuality; enables the use of a tangible interface metaphor for object manipulation; supports seamless interactions between real and virtual settings	The greatest challenge is the need for instructional designers to design learning activities for AR.	The researcher's main conclusion is that AR fosters the ability to transition smoothly between reality and virtuality, which makes it easy for learners to improve their learning.
Giraudieu et al. (2019)	Randomized controlled studies, focus groups and observations	18 teachers and educational trainers	Primary and high school	Enhances collaborative learning; facilitates autonomous learning; and enables real-world pedagogical activities	None noted	The key inferences from this study is that AR enables both collaborative and autonomous learning. The authors refer to this technology as one that enhances students' motivation and engagement.
Martín-Gutiérrez et al. (2015)	Experimental, app development	Six groups of 25 engineering students each	Higher learning	Nice, easy, and useful; promotes student motivation and engagement; allows individualized, autonomous, and collaborative learning; allows the teacher to improve guidance at the training	None noted	The key conclusion from this study is that AR promotes collaborative and autonomous learning among students at higher educational levels.
Chu et al. (2019)	Randomized controlled study; experimental group learning	39 students	Higher education	AR facilitates student motivation; learning achievements are significantly improved	There are still some difficulties in the validity of the research design for AR-based learning settings; promotes critical thinking skills in learners	The key inferences from this research is that AR-based learning promotes students' motivation and engagement, and significantly improves learning outcomes

Table 2. Cont.

Author/Date	Research Design	Participants	Students' Educational Level	Benefits	Challenges	Inferences
Pellas et al. (2019)	Systematic review	No participants	Primary and high school	The review revealed that AR enhances student engagement, increases learners' self-management, influences students' cognitive acceleration, and enriches the learning experience.	None noted	The findings of this study suggest that when AR is incorporated into primary and secondary school curricula, it allows students to self-manage their learning, improves students' cognitive acceleration, and enhances the learning experience.
Bitter and Corral (2014)	Experimental research, app development	No participants	All levels	Allows mobile/remote learning; enhances 3D visualizations for more effective learning; and facilitates the learning of concepts that cannot otherwise be learned in the classroom setting	None noted	The key conclusions from this study are that AR can facilitate the learning of concepts that cannot be otherwise be accessed in a normal classroom setting. It can also enhance mobile and remote learning.
Deng et al. (2019)	Experimental research, app development	20 students	Not provided	AR-based mobile learning increases learners' performance on mathematics exams; has the convenience of mobility; and enables distance and remote learning	None noted	This experimental study showed that AR-based mobile learning enhances learners' performance, and their portability allows the convenience of mobility and remote learning.
Bos et al. (2019)	Exploratory study	Five participants	Not provided	Allows students to learn more effectively; allows learners to focus and remain attentive	None noted	The key findings show that AR can enhance students' focus and their attentiveness.
Diegmann et al. (2015)	Systematic review	No participants	All levels	This systematic review revealed that AR can enhance students' satisfaction, increase student-centered learning, promote collaborative learning, and increase information accessibility	None noted	The key conclusions from this study are that AR in the academic setting can enhance students' satisfaction, promote collaborative learning, and promote learner-centered pedagogy.
Niu et al. (2019)	Experimental, app development	21 elementary students	Primary	If well designed, the researchers argue that AR can help improve motivation to learn and enhance academic performance and satisfaction.	None Noted	The key conclusions from this study is that AR can enhance student motivation, satisfaction, and subsequently, academic performance.
Vate-U-Lan (2012)	Experimental study	484 Grade 3 Thai students	Primary	AR can benefit learners by enhancing creative learning and by improving interactivity and information accessibility.	None noted	The study revealed that the key affordances provided by AR in the academic setting include enhancing creative learning and improving interactivity.

Table 2. Cont.

Author/Date	Research Design	Participants	Students' Educational Level	Benefits	Challenges	Inferences
Elmunsyah et al. (2019)	Survey	30 students	Primary	The survey revealed improvements in students' learning autonomy, encouragement of learning via diverse methods, and improved functions of mobile devices.	None noted	The key conclusions from this study suggest that AR in the academic environment enhances learning autonomy.
Law et al. (2019)	Qualitative study	No participants	All levels	The study showed that AR could enhance collaborative learning and information accessibility; it can also improve learners' engagement, satisfaction, and learning outcomes.	None noted	The major conclusions from this study are that AR can enhance collaborative learning, improve information accessibility, and enhance learners' engagement and satisfaction.
Wu et al. (2013)	Exploratory study, qualitative	No participants	All levels	Key affordances, as reported in this study, were that AR can enhance learners' sense of presence; enable visualizing the invisible; enhance students' immersion and immediacy; promote ubiquitous, collaborative, and situated learning.	Key advantages were found in this study as well as technological, pedagogical, and learning issues.	This study showed that although AR has key advantages in terms of enhancing student motivation and performance, learning, pedagogical, and technical issues need to be addressed.
Wu et al. (2018)	Experimental, app development	50 students from two classes of fourth graders (9–10-year-olds)	Primary	The key benefits reported were that AR can benefit learners in terms of improving their learning achievements	The key challenges in the adoption and implementation included a possible overwhelming increase in students' cognitive load.	The key inferences from this study are that AR can enhance students' academic performance, but there is also the challenge of cognitive overload.
Dunleavy et al. (2009)	Qualitative study; interviews	Six teachers from the core subject areas of English, Math, and Science	Primary; high school	This study revealed that AR can facilitate simulations and interactive and collaborative learning	The key limitation of using AR in education is the complexity of the technology for both students and teachers.	The findings of this study suggest that while AR can provide a variety of advantages, the complexity of the technologies can be problematic for both teachers and students.
Chang et al. (2011)	Experimental study; survey	140 university students	Higher education	The study found that 3D visualizations in AR enhanced students' attention and engagement.	However, the study also revealed that without straightforward designs for the use of AR in education, learners' enthusiasm might be negatively impacted.	The key inference from this study is that AR can enhance students' motivation and engagement, but the current designs are not sufficiently straightforward, which might affect learners' enthusiasm about learning.

Table 2. Cont.

Author/Date	Research Design	Participants	Students' Educational Level	Benefits	Challenges	Inferences
Galati et al. (2019)	Literature review	No participants	All levels	The key benefits of AR in educational settings, as reported in this review, is that it enhances learners' engagement, increases their enjoyment, and supports different pedagogies, including game-based learning and situated learning.	The key challenges or cons to AR application, as reported by the researchers, is that the technology can be difficult to use, it may be very complex for both students and teachers and may also lead to cognitive overload and confusion.	The key takeaway from this study is that the use of the technology may present both affordances and challenges. For instance, it can enhance both engagement and enjoyment in learners but can also lead to their cognitive overload and confusion.
Mitchell (2011)	Experimental	5 middle school math teachers	Primary	The study concludes that the prospect of enhancing students' learning through AR is exciting.	The key challenges reported in this study are that technological issues are key challenges to mass adoption due to incompatibility with current curricula and lack of training on the use of the technology.	The main conclusions from this study are that AR presents an exciting solution for improving learners' engagement in subjects such as mathematics, but technological issues, lack of training, and incompatibility with current curricula remain challenges.
Alkhattabi (2017)	Exploratory research study	200 participants: 115 females and 85 males; age 25 to 55 years	Primary	The study shows there is a willingness to use AR and there is a generally high acceptance rate of its use, given its potential.	The key challenges, as reported in the study, include lack of proper training among teachers, lack of willingness to embrace the technology, and resistance to change.	This study demonstrates that even if there is great potential in terms of learners' outcomes with the use of the technology, some teachers are still resistant to change, and there is still a need for teacher training.
Akçayır & Akçayır (2017)	Systematic review	No participants	Primary	The study reports that AR has the potential to support learning and teaching because it offers teachers and learners the opportunity to combine virtual and real-world settings to enhance students' engagement.	The researchers report a variety of pedagogical issues, such as the need for more class time and inadequate experience in the use of AR technologies. They also noted a variety of technological issues.	The key inferences from this study are that although this technology has great potential in academic settings, there are key pedagogical and technological issues that hinder its implementation.
Elmqaddem (2019)	Exploratory study	No participants	All levels	The key benefits of AR, as reported in this study, are that it enhances entertainment, manipulation of objects, learners' participation, and interactivity.	The study revealed key technical and social problems that hindered the application of AR in academic settings, including uncomfortable devices and health issues.	The key inferences from this study are that AR may be beneficial for improving learners' engagement, participation, and interactivity, but a variety of issues that include health problems may hinder its application in education.

5. Discussion

This section provides the discussion of the study results, thus answering the two research questions provided in the introductory section. Firstly, the chapter presents the discussion of the benefits of AR as derived from scholarly literature. Secondly, the challenges of using AR in the academic context are then presented.

5.1. Benefits of AR in E-learning Contexts

RQ1: What Are the Advantages of AR in Academic Settings as Reported in the Research Literature?

This systematic review revealed that the affordances of AR in e-learning contexts were investigated and empirical and theory-based findings and conclusions were reported. In their study, [18] explored the influence of the introduction of AR on how medical students learned and interacted with a computer-generated 3D skull. The results suggest that one of the most fundamental advantages of AR in education lies in its ability to support kinesthetic learning. Ref. [34] define kinesthetic learning as a form of learning where learners carry out physical activities rather than listen to lectures or teachers' demonstrations. Using a cohort of 30 medical students, [18] demonstrated that AR could improve students' motivation to learn anatomy and their retention of knowledge, while also promoting an interactive environment for students to learn more effectively.

Ref. [18] Also suggest that AR supports kinesthetic learning because it creates an interactive learning system that allows students to understand and memorize content through 3D visualizations. This can allow e-learning students to learn faster and more effectively, even in complex learning situations. The efficacy of this pedagogical strategy on student outcomes, performance, and motivation has been empirically examined and reported by [35]. Similarly, [36] agree that AR allows for the creation of learning aids that promote better interactions, adaptability, and creative engagement among learners. These researchers argue that AR can be implemented successfully in learning settings, including e-learning contexts, to create new pedagogical approaches that foster the development of human-centered learning environments. Essentially, [36] concluded that AR facilitates kinesthetic learning, also known as "learning by doing," which enables faster mastery of the learning content.

AR has also been found to be beneficial in academic settings, as it allows a more efficient visualization of abstract concepts, which in turn, facilitates students' engagement and learning intentions. The empirical evidence is the variety of benefits of AR in academics, particularly in subjects and topics that demand imaging abstractions. For instance, [31] reported the benefits of special visualization enabled by AR in enhancing the ability of students to understand and solve real-world problems. Ref. [37] Agree that the advantage of using AR in educational settings is that it provides better visualization even in complex academic situations, such as chemistry and biology. In most cases, important elements of visual-spatial abilities in e-learning contexts have depended on teachers' drawings or oral descriptions. However, [31] argue that special abilities should not be static, and as such, a dependence on teachers' drawings and oral lectures can negatively affect the learning outcomes and performance of students. The dynamic process of spatial ability can be fostered through AR, in particular, through the interactions of real and virtual objects. Ref. [31] found that AR applications could be used in a variety of academic settings to promote spatial visualization even in complex courses such as Calculus. In a similar study, [38] suggested that current strategies of knowledge delivery should move away from memory-based education toward motivating and creative technological innovations, such as AR. They proposed a paradigm for teaching chemistry called "Augmented Chemistry," in a study, in which they emphasized the advantages of tangible interactions. They concluded that it is vital and academically beneficial for learners to view representations of actual molecules in 3D settings, which allow learning from a variety of viewpoints. Their findings provide a variety of ways through which educators in both land-based and e-learning environments can implement AR using a webcam and open-source software to teach chemistry and other complex subjects and topics.

According to [39], AR can be used to augment collaborative tasks in e-learning contexts. Through this technology, it is possible to develop and implement innovative computer interfaces that can integrate real and virtual worlds to develop better face-to-face and remote interactions and collaborations. Furthermore, a key affordance in the academic setting is that it allows a smooth transition between reality and virtuality. Ref. [40] Reported that interactions and collaborations enabled by AR were more similar to natural face-to-face collaborations than were screen-based collaborations. This affordance was also reported by [41] in their study on the promotion of collaborative and autonomous learning of science practices without the assistance of a teacher. The results showed that students preferred using AR rather than traditional teaching practices, describing AR as “nice,” “easy,” and “useful.” Such findings not only have practical implications for e-learning performance and outcomes but also students’ motivation and engagement. This systematic review of the research literature also found that other studies, such as those by [42,43] supported the findings that AR in academic settings improves learners’ motivation and engagement, especially when game-based approaches are utilized.

Studies by [44,45] investigated the current state of AR application in mobile learning contexts, particularly for wearable devices, both stationary and mobile. Essentially, they investigated selected subject areas of education that have been positively impacted by AR and provided recommendations for applications of AR in these areas. For instance, [44] found that, for the subject area of history, museum guide apps could be used to recreate artifacts, especially where structures have become dilapidated over the years. Similarly, game-based AR applications were found to be useful in educational settings to teach students a variety of subjects and topics through embodiment, play, and practice. The AR applications in the mobile devices, such as iPhones and Android devices, were found to have the potential for positive implications in education when their application was suitable and appropriate. Furthermore, [45] reported that AR was beneficial because it allowed remote and distance learning due to the devices’ portability and convenience.

Studies by [46,47] reported that AR increased learners’ focus, attention, and concentration. Ref. [46] examined a variety of educational technologies and increases in student focus and attention, and found that innovations, such as AR, when used appropriately, could enhance learning by increasing their focus and attentiveness. In their systematic review of the research literature, [47,48] found that the key benefits of AR for learning included increased satisfaction, concentration, attention, and motivation. Increased satisfaction implies that students’ experiences in the learning context rise to satisfactory levels, particularly during the learning process. Students enjoy learning subject areas they would otherwise not engage in during routine teacher–student lectures. For instance, students are reported to enjoy going through library catalogs and solving mathematics and science tasks when AR technology is involved. In contrast, frustration is increased when using a manual or a routine method of accomplishing such tasks. Increased concentration connotes learners’ intensified degree of focus while using AR tools during the learning process. The results of the study by [47] suggest that AR application in learning situations increases students’ physical interactions, which in turn, induces deeper concentration.

This systematic review revealed that learners pay attention to AR as a technology, which they described as being “interesting” compared to other learning approaches. Learners’ attention and amplified interest have been shown to promote their interactions with learning materials. Ref. [47] found that AR-centered approaches to learning tended to increase students’ eagerness, interest, and engagement (also referred to as motivation) when compared to non-AR methods. For instance, when AR-style gameplay was introduced in a learning context, the learners’ intrinsic motivation increased. Similarly, students who used AR books appeared to be much more eager to read and learn than students who used non-AR books. The students who used AR were also found, in the included studies, to be more proactive compared to non-AR students and were often willing to continue to learn through the technology even after the end of the learning session.

The empirical and theoretical literature on the benefits of AR in e-learning contexts cite a variety of other positive implications, see Table 3. Refs. [49,50] found that in similar subject areas, students who

learned using AR tended to score higher on tests compared to those who learned using conventional methods because AR was found to improve students' knowledge retention. Such findings suggest that AR also promotes improvement in students' learning curve compared to other traditional non-AR contexts, with students studying similar subjects and taking similar tests. The study by [51] found that AR methods support creative learning, and thus, produce creative learners compared to non-AR methods. This benefit was related to the method's capacity to facilitate the absorption of new knowledge while solving problems in settings that were more realistic. Other benefits, such as increased interactivity, information accessibility, and improved collaborative and student-centered learning were also reported in studies by [52,53].

Table 3. Summary of the key benefits of augmented reality (AR) in e-learning contexts.

Key Benefits	Authors
Supports kinesthetic learning	[18,36]
Allows more efficient visualization	[31,37,38]
Enhances collaborative learning	[39–41]
Allows distance & remote learning due to portability and convenience	[44,45];
Boosts students' motivation and engagement	[41–43]
Increases students' physical interactions and concentration	[46,47]
Allows student-centered learning	[53]
Increases learning satisfaction	[47,48]
Enhances knowledge retention and spatial abilities	[49,50]
Supports creative learning	[51]
Increases interactivity and information accessibility	[51,52]

5.2. Challenges of AR in E-learning

RQ2: What are the challenges of AR in academic settings as reported in scholarly literature?

The challenges associated with AR in e-learning and learning contexts in general, in the research literature, have been categorized in various ways by different researchers. Most of the studies, such as those by [14,54] have identified three key areas of education where AR is challenging (e.g., learning, pedagogy, and technology), and researchers have provided possible solutions to overcome the challenges. Based on these studies, challenges in the application of AR are related to learners as well as the learning process. Ref. [55] Also reported that learners in AR e-learning environments could become cognitively overwhelmed by the large amounts of content they encounter, the complex learning content they are expected to consume, and the multiple, highly technical devices they are expected to use. This is particularly true when students are expected to set up the devices on their own and multitask to accomplish learning targets. Ref. [55] Reported that students might become confused and astounded when they engage in complex AR simulations because they are required to deal with mostly unfamiliar technologies and complex tasks under intense circumstances.

Ref. [55] Also found that AR challenges the learner and the learning process, especially in subject areas where the learner is required to both apply and synthesize a multitude of complex tasks and skills through spatial navigation, mathematical estimation, technology manipulation, problem solving, and collaboration. These challenges are evident in e-learning contexts where the student is expected to perform most of the tasks and have the essential skills to learn them effectively. Ref. [56] Study also emphasized this challenge, stating that when AR is unassisted, it may confuse learners, which may delay or have another negative effect on the learning process. The general recommendation is to provide the support necessary for students to use the technological devices in AR and the skills necessary during the AR learning process. As reported by [6] this is particularly vital in e-learning scenarios where learning takes place in a virtual world.

Pedagogically, AR implementation in e-learning contexts also presents a variety of challenges and should be taken into consideration when adoption initiatives are planned. For instance, [9,14] reported that, like many other technological innovations, there is often resistance from teachers to adopt AR to

replace their conventional approaches to instruction. The learning activities that often characterize AR learning include studio-based pedagogy and participatory simulations. Such approaches typically contradict and are quite different from the usual teacher- and delivery-based methodologies [57]. This difference in approaches has been shown to hinder the implementation of AR in academic settings, such as e-learning contexts. Related to this challenge is the lack of necessary training in effective pedagogies that can aid both the adoption and implementation of AR [6]. This lack of training among teachers on how to implement AR effectively in their usual instructional settings was found by [8] to have a negative effect on instructional design. Ref. [14] also found that lack of proper teacher training caused confusion even for teachers as they attempted to distribute information between the two realities and among the devices. These studies recommended extensive teacher training on AR implementation in various academic settings to help in their transition to AR and resolve these problems.

Technological challenges related to AR adoption and its implementations were examined in the included studies. Ref. [14,58] reported that one of the fundamental challenges to incorporating AR into learning situations is that the cumbersome and often expensive AR equipment may cause discomfort and poor health for the users. Ref. [8] Found that some technical issues, such as poor connectivity, expensive technology, low sensitivity in recognition triggering, GPS errors, and technical problems could frustrate the entire learning process. Ref. [14] Recommended adopting AR technologies that can detect the differences between reality and fantasy to avoid confusing both the teachers and students. They also acknowledged that issues of device integration, stability, and failure could be solved by the current rapid advancement in AR technologies that offer devices that are more stable, portable, and wireless. A summary of the key challenges is listed in Table 4.

Table 4. Summary of the key challenges.

Key Challenges	Authors
Information/cognitive overload	[14,54,55]
Complex technology for both students and teachers	[55]
May be confusing and overwhelming to both students and teachers	[56]
Lack of necessary skills to use AR technologies	[6]
Teachers' resistance to adoption	[9,14]
Incompatibility with the usual pedagogical approaches	[6,57]
Lack of training and knowledge among teachers about using AR in education	[14,54]
Technology is expensive	[14,58]
May cause health and discomfort concerns for users	[14]
Technical problems, such as poor connections and Global Positioning System (GPS) errors	[8]

5.3. Recommendations for AR Development

As mentioned previously, this systematic review describes some of the technical problems that challenge the mass adoption of AR in educational settings, such as e-learning contexts. To circumvent such issues, developers must take advantage of advancements in technology to enhance various aspects of AR technology. For instance, most mobile and laptop cameras are currently made for capturing 2D videos and images, and thus, do not render good 3D images. Similarly, the current GPS readings are precise, but only up to 6 m; however, greater accuracy is needed for deploying AR markers. AR developers in academic settings need to enhance accelerometer reading using protocols, such as the exponential smoothing technique, as described by [59]. Camera performance can also be enhanced by using approaches, such as the 2D QR and bar-code markers, as suggested by [60]. In terms of cumbersome (heavy) devices, developers should focus on using lightweight materials to reduce their weight significantly and address health-related concerns, such as neck pain. Currently, Microsoft Compact is developing a lightweight AR prototype that has benefits for academic environments, both online and on-site. During the development of new AR devices, methods for complete eradication of potential eye problems also need to be considered. Many issues with software

inter-operability in academic settings must be addressed, as does how the current technology can be seamlessly integrated with traditional pedagogical approaches.

5.4. Recommendations for Education and Training

To increase the acceptance and use of AR in e-learning contexts, student and teacher training on how to use the application are needed. Ref. [6] Identified this need, arguing that lack of training is a major cause of deployment and implementation challenges. On-the-job training for teachers not only can facilitate the implementation of AR in e-learning contexts, but it can also resolve the challenge of resistance to AR and hasten its swift adoption. The applicability and use of AR should be incorporated into teacher training courses and students' curricula to equip future teachers and students with the necessary knowledge of AR technology and to ensure their ongoing use of it.

6. Conclusions, Limitations, and Future Directions

In the rapidly developing embryonic world of technology, AR is no longer a new concept, and with the concurrent rise of e-learning platforms, AR's significance in education is growing as well. This systematic review revealed that AR amalgamates modern technology with real-world settings to provide an immersive e-learning experience for learners. The benefits of using this approach in e-learning contexts include, but are not limited to, the enhancement of kinesthetic and collaborative learning, the enabling of high-risk e-learning in real-time, as well as visualizations, the support of real-world simulations with interactive objects, and the increase in learners' motivation, satisfaction, attention, and content retention. However, the research literature on AR also indicated challenges to its adoption and implementation, specifically, its learning, pedagogical, and technological issues. Regardless of the challenge, training and continuous education were viewed as viable solutions to the key issues in AR adoption in e-learning contexts, although the field is still reliant on technological advancements in this area. This systematic review is the only current study that has examined the benefits and challenges of implementing AR in an e-learning setting. The few existing studies of this nature have only attempted to identify the advantages and disadvantages of its use as a supplementary approach in an on-the-premises classroom-learning environment.

The main limitation of this study is that it identified the benefits and challenges of using AR in e-learning contexts based on findings from empirical studies that may have limitations in terms of research design and evidential validity. This limitation is accentuated by the fact that the applicability of AR in education is still in its infancy, and more research is needed. Given this, future directions are suggested for future studies. First, although the use of AR within the classroom environment provides academic benefits, future research on how effective this approach is for distance and remote learning is needed. The measure of its effectiveness is vital for education, given that learners' attentiveness and competence in the use of technology vary considerably. Second, in relation to the first future direction, there is a need for more research on the pitfalls of using AR and how to mitigate them in educational settings. For instance, some studies have reported that using AR in education can result in cognitive overload for the students. Learners might become overwhelmed by the complexity of the platform or the amount of information displayed. Future research should investigate how such detriments to learning can be overcome or mitigated to enhance the efficiency of AR in improving academic outcomes. Third, future studies should investigate the effects of AR on the development of long-term memories. Although theoretical perspectives on this have been developed, there are no empirical studies on how AR can effectively create long-term memories in students. This investigation is particularly important for improving learners' retention in studies conducted on the use of AR in educational settings.

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