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PAPER

Augmented Reality Awareness and Latest Applications in Education: A Review

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ABSTRACT

Several advances in technology have touched the educational sector, where improvements and enhancements are always a surge for innovative learning. Augmented Reality (AR) is considered an efficient and promising technology capable of enhancing the educational sector. AR is a visualization technology that allows human interaction by providing users with a perception of reality using virtual information. In other words, AR adds to the existing real-world environment some extra virtual information generated by computer techniques that can enhance the overall experience. This promising technology can be applied in different sectors such as education, healthcare, banks, tourism, etc. Despite the great work available in the literature about this topic, deep insights and extensive research are still needed before the actual implementation in the real world. The aim of this work is to highlight the importance of AR in improving the educational sector and increase awareness of using such an approach. A review is conducted to prove the validity of AR in increasing learning outcomes, students' motivation, and engagement in classrooms, as well as improving the understanding level. Several papers were analyzed based on different application areas under various interdisciplinary databases. As a result, the papers were collected in a table-based format to provide researchers with better and easier insights on how to improve the use of AR in education before real implementation. This study helped in highlighting potential future work, discussing limitations, advantages, disadvantages, and the latest advances in this technology.

KEYWORDS

augmented reality, awareness, education, innovative learning, human-computer interaction, immersive technology

1 INTRODUCTION

Currently, we live in a society in which data and communication technologies have developed a practical value in all social sectors, especially in education. Augmented reality (AR) is a technology that integrates multiple virtual objects on

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top of real-world ones. These virtual objects then appear to exist in the same space as the real world. So, the use of AR technology in education is acknowledged as the first application field to have a bright future. Augmented reality (AR) is a technology that combines the virtual and real worlds, allowing computer-based virtual objects to exist as real in our real life. It has been used in many fields, such as healthcare, manufacturing, agriculture, and art. Still, it is most popular in education due to its impact on learning outcomes, motivation, learning process, visualization, and more. ([1]; [2]). The integration of AR with Artificial Intelligence (AI) opens a new direction for developers and researchers to explore and make decisions [3]. Integrating AR in education provides an interactive way of learning which is more attractive and motivational for students. AR techniques have completely changed the learning process [4]. Some applications of AR in education include but are not limited to studying molecules in chemistry, studying anatomy or performing a virtual surgery in medicine, studying DNA structure in biology, exploring electron movements for electrical engineering students, visualization of memory updates while programming for computer science students, and much more. Adopting AR and involving students with such visualization increases interaction and improves their motivation for learning. The learning process is much easier, more precise, fun, and more engaging than traditional learning methods. AR is a self-paced learning method that accelerates learning and makes it more interesting for students. It can be applied to any subject. The educational institutions' curricula must be updated to reflect new teaching methods. Paper [5] provides an example of using an AR-based system to demonstrate how an AC generator operates. The results were incredibly beneficial and valuable. The usage of AR in several learning fields was covered in Godoy and Carlo's work [6], where virtual physical items were used, resulting in an innovative campus for the academic community. This paper covered AR in the context of English education, foreign language instruction (in Arabic and French cases), ICT instruction, scientific instruction, social science and history instruction, vocational training instruction, and mathematics instruction. As a result of the study, AR effectively supported the different instruction types [6]. A potential future work can include the integration of AR along with game-based learning (GBL) to improve the education sector. The author in [7] discusses the latest trends and scientific findings in AR, its applications, and uses in teaching, learning, and training. The paper lists several AR tools and identifies a way of selecting the appropriate one. Njhawan et al. studied in their work the level of AR awareness and its use among teachers and users. Factors like target audience, technologies, challenges, and advantages of AR have been discussed [8]. Murat and Gökce also discussed the advantages and challenges that can be faced in the education sector with the adoption of AR [9]. They also studied the impacts of AR on education and concluded that even though AR is still limited in classrooms, this technology promotes an enhanced learning process. However, one of the main challenges faced is the awareness and capability of students to deal with this technology. The authors also discussed augmented reality and how it is related to or aids in educational contexts, including the advantages and challenges associated. Authors have found that AR improves learning performance by delivering well-integrated and relevant content such as images and videos. Their studies also demonstrate that AR can enhance learning motivation and enhance satisfaction since it increases enjoyment and engagement. It is also stated that AR improves spatial ability, which leads to the conclusion that AR technology may improve pupils' learning performance. Another significant outcome of the article is that AR improves communication and relationships between teachers and students. In contrast, they

mentioned that the most challenging aspect of AR is that it is tough for students to use. Using AR without a well-designed interface may cause students to struggle with this technology. Another issue highlighted is that employing AR may result in time loss because teaching such advanced technology and ensuring students become familiar with it can take longer than planned. Another outcome noted was that students might feel cognitively overloaded while learning AR due to the challenges' complexity and the content volume [9]. The author of paper [10] presented a literature review to describe AR technology and its application to education and training, along with potential impacts on the future of the education sector. The most recent developments in education, including augmented reality, are discussed in paper [11], together with their potential applications for Industry 4.0. AR facilitates teachers' work since the information is available in real-time on their own devices, which can improve students' autonomy. Since literature still needs extensive studies about how AR contributes to education and how content type can affect learning outcomes, Hincapie et al. studied this issue by exploring several databases and understanding the state-of-the-art in this field. Analysis showed that there is no preferred methodology for designing AR content. However, content creation can vary based on the user's experience [12]. Therefore, if integrated with well-trained users, AR can change the classroom environment to a more enjoyable and engaged class. Lesson contents will be presented in a more comprehensive way which can improve students' skills, increase their motivation, promote collaboration, and generate a positive environment [13]. Figure 1 presents a comparison between traditional learning and AR-based learning.

The author in [14] explores the potential applications of augmented and virtual reality tools for private instruction, such as Google Glass and Oculus Rift. According to various studies and reviews, using AR/VR in education led to more students that are receptivity and improved outcomes for both students and teachers. The use of AR/VR technology boosts attention by 60%. A list of positive and negative impacts of AR adoption on students' learning process is identified in papers ([15]; [16]; [17]; [13]). Ibanez and Delgado-Kloos emphasized in their study how powerful AR is in supporting teaching and learning. Authors highlight the significant impacts of AR in increasing motivation, engagement, interaction, and collaboration and thus improving performance [18]. Figure 2 depicts the advantages and disadvantages of AR in education. Some of the limitations from the student's and teachers' perspectives are discussed in paper [19]. In this context, Tzima et al. studied the level of acceptance of teachers and students for adopting AR in developing its applications. Results showed that the development of these applications could be feasible depending on the content of the curriculum and the degree of cooperation among teachers. Thus, considering teachers' personalities and readiness to accept such integration is a limitation to adopting AR in education practices [20].

As discussed earlier, augmented reality allows you to experience reality in a better way by overlaying virtual objects on natural physical objects. Users will then feel that this digital information, such as audio, text, video, images, or 3D objects, is in the same place as the real physical ones and appears as part of the natural environment. AR applications can be classified under two different categories: image-based and location-based. For location-based AR, the application will be triggered based on the user's arrival at a particular location. The image-based category can be divided into two sub-categories: marker–based and marker-less [21]. Virtual content is visualized by predefining target images at different places using marker-based AR techniques [22]. These images are scanned using a camera, and then the system displays the 3D visuals on the surface of that image. On the other hand, no predefined

target images are used with markerless AR. Brito et al. have conducted a comparison study to show the differences between the two techniques [23]. Ibanez et al. identified AR in their work as image-based and location-based. Registering the position of 3D objects on a real-world image requires specific labels and global positioning systems (GPS) to identify the location of real objects. After detecting the position, the AR system adds digital information such as images, videos, or 3D models on top of the real object. As a result, the digital object seems identical to the real object. Then, the user can observe the object from different perspectives through a smart device (tablet, mobile, etc.) [24]. Better said, maker-based AR allows users to scan markers using their device camera to trigger an augmented experience. This process requires a QR code or a trigger photo to activate the experience. Users, moving around the marker, can see the digital experience in 3D. Whereas with markerless AR, no markers are to be scanned. An app or web can be launched which scans the real environment around the user and positions the digital object on a flat surface. According to the authors in [25], AR is important in education because it affects students' participation levels, improves collaborative learning, and increases interaction between students and their tutors. There are five types of AR applications: discovery-based learning (DBL), object modeling (OM), AR books, game-based learning (GBL), and skill training. DBL is most commonly found in museums and astronomical education. When looking at different perspectives of an object, OM is the best, and it is usually employed in architectural and human anatomy instruction. AR books, which provide 3D presentations using special glasses, were employed in the education of youngsters. GBL is when gaming and education are merged, and tutors typically employ such techniques to clarify complex ideas.

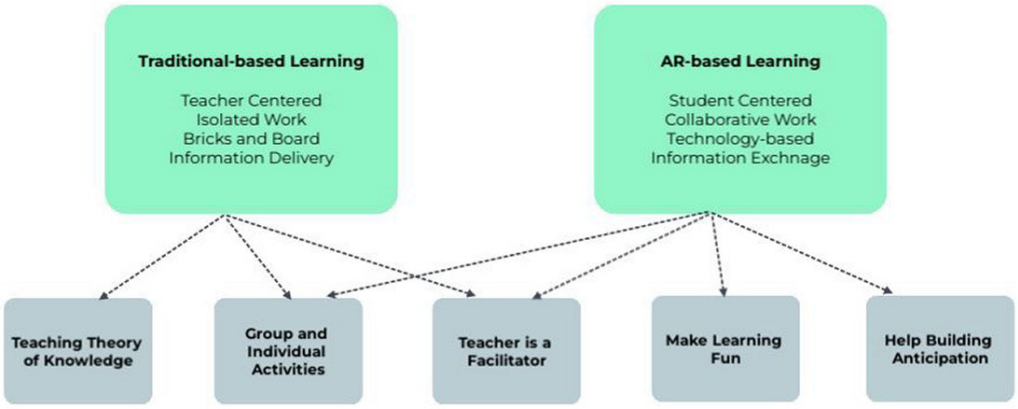

Fig. 1. Traditional vs. AR-based learning

The proposed game-based learning concept focuses on using AR technologies in games associated with supported learning. According to the authors, AR is defined as a combination of three dimensions of computer-generated objects and text overlapping on top of real-world events. However, virtual reality (VR) occurs when virtual data replaces physical data, resulting in a new reality. It is also stated that our imagination only limits AR and may be used in any activity, course, or even habit as long as it falls inside our creativity circle. Augmented reality is most utilized in engineering and architecture degrees, particularly in courses that require practical experience to become acquainted with the material [26]. The Polytechnic University

of Valencia is a crucial university employing AR methods to assist primary education instructors with mathematical didactic work. AR simplifies education by allowing us to divide complicated objects, such as 3D objects, into phases, pieces, or stages and allowing students to test and explore the material from many perspectives. It is also claimed that AR has increased student participation and improved interaction between the teacher and the students by having a better learning atmosphere and environment. However, the main challenge for AR is training and developing the procedures that will allow this technology to be used in education. By saying that, this article emphasizes that more research needs to be conducted to determine if AR can make education easier and that the behavior of AR in education should be explored more. Tekederea and Gökera concentrated on how to compile studies on AR utilization in the educational sector. They classified the research articles based on their subjects, years, intended audience, and efficiency levels. They used the meta-analysis method, combined the results of the efficiency of AR in education, and measured the efficiency of these applications. The meta-analysis method categorizes similar studies on the same issue and evaluates the quantitative data of these investigations. Initially, 171 papers were examined during the scanning process; however, after applying specified criteria, the studies were cut down to 15 reviews. As a result, they discovered that the AR-incorporated applications had moderately more beneficial effects on students, which should not be ignored. Their study suggests that AR improves academic success and desire for learning by making key concepts clear and pleasurable to understand while also increasing students' imagination [27].

This paper is organized as follows. Section 2 focuses on the related research highlighting the importance of integrating AR in different aspects of the education sector. Section 3 and Section 4 describe the techniques of implementing AR and the hardware/software needed, along with the latest developments in this area. Section 5 is dedicated to discussing the results where the output of this study is presented through a table covering all data gathered, including limitations and potential future work. This project's future work and contribution are presented respectively in sections 6 and 7. Section 8 concludes the paper.

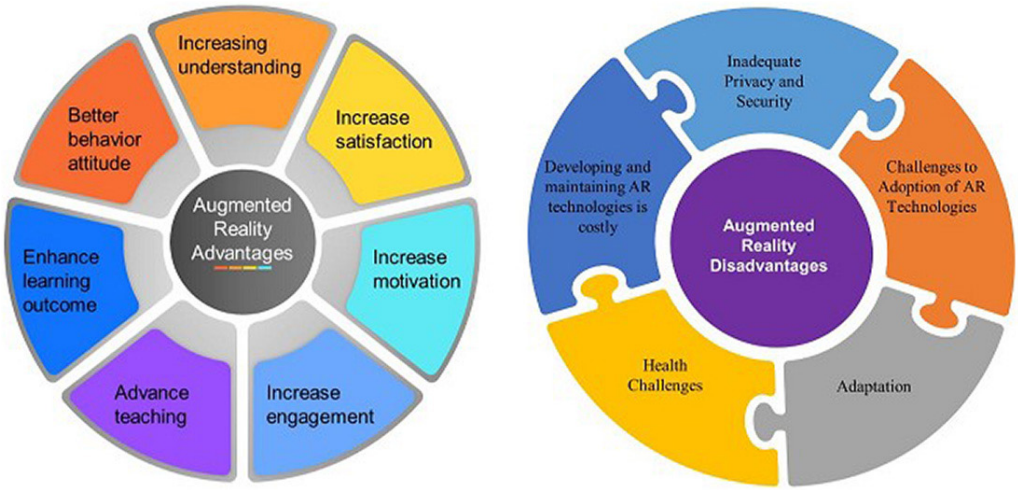

Fig. 2. Augmented reality advantages & disadvantages

2 LITERATURE REVIEW

This section provides a detailed overview of different applications and studies in the literature for effective learning using AR technology. Several databases were explored, including IEEE, Elsevier, Springer, MDPI, and more. The adoption of AR in education has been studied with different levels of learners, from childhood students to university students, including special needs and students with disabilities. Studies also focused on various topics such as healthcare, engineering, mathematics, chemistry, and more. In this context, the related work is presented below.

2.1 Surgical and healthcare education

Current challenges in surgical studies led researchers to consider the potential of deploying augmented reality as a method to improve education in this sector. Joshua et al. performed a study to evaluate the validity and effectiveness of AR as an educational tool for surgical studies. 6,500 studies were investigated in this work, and the results were promising, yet additional investigation is needed before real-life implementation [28]. McCarthy and Uppot studied AR platforms' impact, challenges, and potential role in healthcare education. Using AR, teaching anatomy, medical training, and simulation of emergencies can be easily achieved [29].

2.2 Geography and astronomy education

According to Shittu et al., the integration of AR in geography teaching can be enhanced with the use of an augmented reality instructional tool (ARIT); this technology affected learners' performance in a significant way [30]. Lindgren et al. applied AR technology to teaching astronomy. The authors conducted two different sessions to validate the integration of AR. They conducted the class using a computer system in one session, and in the other session, they integrated AR technology. Results were encouraging in the second session, where more interaction with the users was noticed [31].

2.3 Primary and pre-school education

Muhammad et al. developed a few applications based on AR technology for primary school students. These applications aim to test students' progress and provide performance evaluations where students can interact with their books' content when displayed virtually via intelligent devices such as tablets, laptops, or mobiles. In this study, the authors investigated the effectiveness of AR-based learning in terms of attitude, performance, behavior, and motivation. Results show a significant enhancement, and thus the importance of adopting AR techniques in the learning process [32]. Other researchers used AR to teach the English alphabet to preschool students. The AR-based system improved the level of participation in the classroom compared to the traditional method [33]. Rossano et al. proposed an AR application named Geo+ to support primary school students in acquiring knowledge of solid geometry. Results showed that Geo+ is effective in student learning, where students found it easy to use and engaged effectively in the classroom [34].

2.4 Special needs students

Integration of AR as a motivational learning method was even tested with special needs students and resulted in positive outcomes [35]. Kellems et al. also used AR to teach mathematics to middle school students with some learning disabilities. They used video-based instructions to conduct the training process. All considered participants showed significant results and improved problem-solving skills [36]. Köse and Güner-Yildiz also studied the use of AR as a learning material in the education of special needs students. Results were positive and promising [37]. To know what the impacts are of using AR with students with educational needs, the authors in [38] highlighted the experiences with AR that are being carried out with low-performance students who need educational assistance. They studied the impact of the use of AR in the field of special education indicated in the studies analyzed and the conceptual structure of the scientific literature published on the use of AR in special education. The authors analyzed 18 articles on AR applied to learners with educational needs. The use of AR has a short history in special education. However, the scientific production in this field during the period 2016–2021 is continuously increasing, and there are more and more areas of knowledge where this technology is used in these students' teaching–learning process. Based on the study, the authors conclude that AR technology has proven appropriate for the exceptional education environment, improving teaching and learning opportunities and educational success for students with educational needs. The results of this study are proposed to provide vital information for teachers wishing to implement AR technology in the education of those students.

2.5 STEAM education

The topic of AR integration with education is quite new, and little research was conducted in STEM education, which implies a surge of extensive research to validate the case. STEM Education involves educating students in the four specific disciplines of Science, Technology, Engineering, and Mathematics. Authors in [39] reviewed the work done in the area of STEM education, described the concept of augmented reality, and analyzed augmented reality technologies that can be adapted to teaching natural and mathematical disciplines. The role of the STEM approach with augmented reality in the educational process is determined. STEM requires practical activity in labs using specialized tools. STEM and AR technology allow stimulate students to creativity, to develop their scientific and research skills and abilities to implement current competence in their life. This integration proved the ability of AR to organize teamwork and stimulate group cooperation. The paper covers a case study using AR in a robotics project. Since schools generally lack developmental resources with no room for experimentation because of the overloaded curriculum, Jesionkowska et al. proposed a new method based on active Learning [40]. This method encourages students in different STEAM (Science, Technology, Engineering, Art, and Mathematics) subjects as part of the learning process to build an AR application. Active learning is a student-centric approach that encourages students to be part of their learning process. It usually promotes their problem-solving skills and awakens their curiosity, leaving room for motivation and creativity. The applicability of this method is evaluated through a case study and found to be promising where students enjoyed learning using the AR approach. Learning about macromolecules

has always been a challenge in chemistry. A study targeted junior high school students and their ability to visualize microstructures correctly using AR techniques during chemistry experiments. The designed AR-based system allowed students to interact with these micro-particles, and the tool was assessed as being very effective [41]. Chiu et al. demonstrated the effectiveness of adopting AR in teaching gas properties. Students made significant progress in understanding gas behavior at the molecular level and thus the importance of AR in enhancing science learning [42]. Lai and Cheong offered a survey about extended reality (XR) effects on the educational sector, particularly in the mathematical field. Virtual and augmented reality are the fundamental components of extended reality (XR). The use of XR in education has a wide range of theoretical and practical uses. Many students can hear about real-world experiences from instructors [43]. Almenara et al. stated in their research that the use of AR demonstrates a high level of motivation and creativity towards the courses taken because students are encountering a new technology with complicated problem-solving techniques rather than a null way of learning, such as traditional studying. Similarly, testing results have demonstrated that AR enhances students' confidence, pleasure, and performance. However, the tests conducted did not demonstrate whether or not using AR was simple, as the testing results in this area were neutral [44]. The authors used different methods to get their findings, such as the TAM (Technology Acceptance Model) test to assess student acceptance of AR technology in educational settings and the IMMS (Instructional Materials Motivation Survey) to assess students' levels of attention, confidence, and pleasure after utilizing AR items.

It is very important to apply the theoretical concepts taught in class for different engineering fundamentals to improve students' intellectual level and reach the desired learning outcomes. In courses that lack interaction content, students are not motivated and thus disengage during class. Proper visualization is essential in this case for a deep understanding of engineering concepts; therefore, introducing a new tool far from the traditional learning method is essential. Augmented reality can be adopted here to fulfill this goal and achieve a more interactive classroom with more engaged students. Kaur et al. investigated how AR can enhance student motivation toward learning and improve classroom interaction, specifically in engineering fields. A questionnaire was designed after a class was conducted using AR to retrieve satisfaction, relevance, confidence, and attention results. The output of this questionnaire was very positive, which proves the efficiency and impact of AR on students' learning [45]. Based on research done in this field, it was proven that students are more engaged in a lesson when motivated to learn. The utilization of AR improves the ability to understand and increases motivation by offering the potential of visualizing the material for better outcomes and a promising academic performance ([46]; [47]). Baran et al. research in this area aims to develop and evaluate an AR application to teach electrical circuit courses to fifth-grade students. Students' attitude towards this technology integration was examined. Two approaches were considered: group work and individual work. Results showed that AR technology had higher impacts on students studying individually than those studying in a group [48]. Ibáñez et al. designed an AR-based learning tool for ninth-grade students to teach basic principles of electricity [24]. Al Najdi examined the effectiveness of using AR to enhance student performance using books containing QR codes. This study showed higher performance in students using these textbooks than those using normal ones, considering that students did not face difficulties

integrating technology into their learning process [49]. According to Al Najdi et al., AR technology allows students to observe and learn and thus to test the theory by applying the concept in real work using virtual information. Authors explained that results showed a higher student performance and a better motivational environment [50].

2.6 English and distance learning

Dalim et al. used TeachAR, an AR-based tool for teaching essential English words using shapes, colors, and prepositions. The tool is based on speech recognition that helps non-English speaking students interact with the application, thus leading to higher engagement and better results [51]. Authors in [52] studied the effect of AR on distance learning. They used a quantitative research method to measure the performance of 422 university students. From data collection and analysis, results were promising, and students were well interested in the technology.

2.7 Training and informal learning

Wang et al. explored the development and use of AR by presenting arguments in favor of and against its usage as a teaching tool. Three categories can be used to categorize AR devices: 1) Wearable technology, such as head-mounted displays, smart glasses, and gesture recognition systems. 2) Handheld using cellphones and tablets. 3) A computer monitor shows a fixed screen [53]. It also outlines learning theories like constructivism and twenty-first-century skills that aid teachers in integrating augmented reality into the classroom. The study covers four case studies: AR in instructional learning activities, AR in constructionist learning, AR in collaborative learning, and AR in informal training. It showed improvement in the learning outcome and enhancement of pedagogical contributions and was easy for students. Sáez-López et al. presented a study to investigate the impact of augmented reality on initial teacher training and the appearance of such practices in the educational environment. The survey methodology with mixed questions was the primary method employed in the study. The Wilcoxon test was used for the pre-test design to establish a baseline and compare survey results. When the survey was implemented, numerous software programs, including Autodesk 123d, were employed to convert the images into augmented reality figures that could be easily seen using SketchUp. According to the survey results, it is evident that most students agreed on a reasonable assessment of AR. Many researchers stated that AR is appealing and encouraging to work with since it fosters innovation and involvement among pupils. Another thing that most students agreed on is that they see AR as a tool for the future rather than a present instrument due to the absence of implementation of such devices in educational settings. On the other hand, when it comes to the drawbacks of AR, some students claim that it is a time-wasting and distracting method of learning, which they attribute to the intricacy of AR. Furthermore, many pupils had terrible experiences with AR due to a lack of teacher training at that time and the exorbitant expense of implementing such a technology. However, it is trustworthy to mention here that the number of these students was small [54].

2.8 Vocational and formal education

Lester et al. examined the use of AR in vocational teaching materials in the case of chemical industry training in Germany. AR has advantages for low-risk physical tasks. The study demonstrates that using AR reported improved learning outcomes and higher learning attainment [55]. Despite the increased time to accomplish the approach, students found it a simple learning method. Additionally, the usage of AR made visualization more efficient and helpful. Saltan et al. offered insights into the adoption of AR applications in formal education, explored the advantages and implications of using augmented reality in formal education and suggested better integrating AR with educational settings [56].

2.9 Gamification

Nincareana et al. showed in their work a variety of AR experiments and their outcomes. AR was classified into two approaches: broad and restricted. The first strategy involves employing synthetic cues to supplement natural feedback to the operator, while the second involves using a transparent head-mounted display. Each experiment was carried out with a single tool/app and on a specific subject taught. Many tools and programs were considered, some of which are:

1. Virtuoso, an educational game in which a collection of artworks is sorted.
2. CONNECT, a project that employs MAR technology to assist students in accumulating content via a head-mounted display.
3. Alien Contact, a game focusing on arithmetic, language arts, and reading skills.
4. ARGreenet, a game created to promote awareness about recycling and its importance to the environment.

These games demonstrated more student involvement and motivation than similar activities run using traditional teaching approaches. The examples offered above were of games created utilizing AR and deployed in a teaching environment with several capabilities, such as context awareness and connectivity. Since the article was based on stating experiments, there was little to show in the conclusion, but the thing that most games had in common was obtaining higher levels of engagement and learning performance [57].

2.10 Physical education

Regarding physical education, there is no doubt that AR is a cutting-edge technology. Guerrero et al. performed a comparison between such a technique and traditional teaching. Many applications, including the AR approach Aurasma, were employed, and studies were conducted to demonstrate the importance of AR in education. Their study included 140 students divided into two groups; one taught using traditional educational methodologies and the other utilizing a more innovative methodology that included augmented reality. One significant advantage of using AR in physical education classes is that it is regarded as a powerful weapon against obese pupils

because it simultaneously merges the virtual and real worlds. Similarly, children who received an AR-based education showed increased motivation and interaction and even increased teacher satisfaction. According to the findings, AR substantially impacts education, particularly in physical courses where motion is essential. Those who used AR were more engaged and did better than students taught traditionally. This clearly demonstrates the usefulness of augmented reality in educational settings and why it should be used more frequently in this discipline [58]. Liu et al. proposed a model for augmented reality-based physical education in schools [59]. This model is built on many technologies, including a cloud network, the Internet of Things (IoT), and remote users. The outcomes of using AR were promising and positively increased the learning ability with a better performance in students' engagement in sports.

2.11 Computer science and programming

Theodoropoulos et al. investigated how AR influences and enhances the learning process in Computer Science (CS) education [60]. To further understand how AR affects programming education, 31 studies were included. Technology's development, potential difficulties, and effects on student learning were all examined. AR achieved considerable benefits in aiding CS learning.

3 HARDWARE AND SOFTWARE

With AR techniques, the learning environment becomes enjoyable and more motivational. Positive outcomes are achieved in designed AR-integrated content, always leading to positive outcomes. In this section, Tables 1 and 2 list, respectively, the hardware (HW) and software (SW) needed while adopting AR in any educational environment. AR devices are generally user-friendly, small in size, light in weight, and highly portable. We can find them in different aspects; either handheld using smartphones, head-mounted using glasses, or wearables using pendants [22]. Another contributing factor encouraging the acceptance of AR in education is the low cost of deployment with the availability of low-cost smart devices. Historically, Smartphones have been the first devices to use AR, especially the Apple iPhone 3GS. Later, Tablets, such as Android-based devices by Samsung (Samsung Galaxy Tab) or Apple's iOS-based iPad, followed it. In 2012, Google advertised its project "Google Glass." Since 2017, Smart Glasses and AR Headsets such as HoloLens, Meta2, and Magic Leap have come to the attention of the pace-gaining developer scene. The creation of AR-optimized hardware by both firms is becoming more and more feasible due to the release of new core AR technologies by Apple ARKit ARCore and Google as a component of their respective operating systems. In Table 1, different smart devices are listed, along with their advantages, disadvantages, and potential use in the educational sector as part of the hardware to be used when adopting AR. The technology behind these devices falls under the software used to develop the hardware. In Table 2, the different used software, along with their description, are listed.

Table 1. AR hardware

HW	Advantages	Disadvantages	Examples	Field of Use
Smartphones and Tablets	Widespread among end users Always present with end users Typical platform to spread apps that are used daily	Heavy to use Small image detail, no true 3D vision, limited interactivity	Phab 2 Pro ZenFone AR	Text, graphics, video, and audio that may be applied to a student's real-time environment
Smart Glasses and Headset	Especially made hardware profiles for AR application branches	Weak to no AR functionality	HoloLens (AR-Headset)	Science
	Hands-free interaction via gesture and voice recognition	Narrow field of view Open questions regarding data protection and privacy	Meta2 (AR Headset) R7, R8 and R9 Series (AR Smart glasses)	
		The technical infrastructure is a major challenge	Google Glass Enterprise (Data Google)	
		Expensive	Monitor less (Data Google)	
			Vuzix M 300 (Data Google)	
AR contact lenses	Can be used in the medical sector	Expensive	Mojo Lens Inwith	Medical Simulation

Table 2. AR software

SW	Description
Vuforia	Vuforia toolkit is considered one of the best platforms when it comes to AR development. It offers an impressive set of useful features, making it a top choice for many developers. It supports both Android and iOS.
AR tool kit	ARToolkit is a popular option as an open-source tool for AR-based applications development.
Google ARCore	Google is one of the top leaders when it comes to digital innovations. Features of ARCore include monitor tracking, light estimation, environment understanding, and much more.
Apple AR kit	ARKit was announced in July 2017 and is compatible with any Apple device starting from iPhone 6s or devices released not later than 2015. It is free.

4 LATEST DEVELOPMENTS

Throughout the years' AR applications in education went into three phases [3]. The first phase covers the period from 1995 to 2009 and is defined as hardware-based AR. AR systems were considered expensive and complex during this phase because they used devices such as head-mounted displays and heads-up displays. All these systems were proposed to explain topics related to health, natural sciences, or engineering and focused on bachelor students as target groups. Applications of the first phase presented some limitations, especially high costs and the application's ease of use The second phase covers the period from 2010 to 2019 and is described as application-based AR, as the AR experience focused on AR applications rather

than AR hardware. This phase began with a significant increase in the number of AR applications for education, and it comes as a solution for the problems faced in the first phase. As humans become increasingly dependent on mobile devices, the adoption of augmented reality technology will begin to rise. AR software advances will be the way forward as the majority of consumers have a smartphone and already hold it everywhere with them, making it a convenient medium to bring AR to nearly every consumer and removing the need to purchase additional and expensive devices and somehow assuring that users could easily use AR applications. This phase was supported by the release of the famous public version of Google Glass in 2014 and Pokémon Go in 2016. Finally, the third phase runs from 2020 forward, and the main components are smart glasses and Web-based AR. Augmented reality hardware is still behind the times. That being said, there is a big opportunity for developing a practical augmented reality headset. Wearable tech is slowly becoming the norm, and as this trend continues, people might be more receptive to AR hardware. So the future of AR appears to progress beyond head-mounted displays and smartphones, with three main developments that have appeared lately: smart glasses, WebAR, and AI. The first development introduced stand-alone headsets such as HoloLens, and the upcoming iGlass, which are a new generation of smart glasses. The second development, WebAR, acts as a solution for the hesitancy of some people to experience AR via smartphone applications. Finally, the third development combines AR and AI to create solutions to different problems of everyday life. The topic of AR is still not mature, specifically when being applied to education, and more advancements are to be experienced in the future for the sake of a better educational sector.

5 DISCUSSION AND ANALYSIS

This section presents the results from reviewing and analyzing 60 articles related to AR in education published in several indexed journals for the past ten years.

5.1 Discussion of results

The review helps increase awareness of AR, especially in the educational sector. Many factors could be extracted related to the use of AR, such as advantages, disadvantages, limitations, and challenges. All studies proved the great potential of AR in the education sector, allowing learners and educators to interact with each other and offering a better learning environment. It was proved that AR affects students' understanding, interaction, and engagement. It also positively affects students' grades and grasps their interest. Articles from different databases are classified in Table 3 to present a review of AR and its efficiency as a promising technology. These reviewed articles also helped analyze the needed hardware and software to implement an AR application and present the latest developments in this field. Any scholars have researched AR, but this technology still needs to be completed. Since this technology has great promise and a bright future, particularly in the educational sector, this work aims to raise awareness and provide a pathway for researchers to use it.

Table 3. Review of AR in education

Ref.	Publisher	Year	Overview	Topic
[52]	iJET	2022	Effect of AR on distance learning of university students. Quantitative research method is used to measure the performance of 422 students. From data collection and analysis, results were promising	Effectiveness of AR on distance learning
[8]	IEEE	2021	Understanding how much teachers are aware of AR and its use. Factors like target audience, technologies, challenges, and advantages of AR have been discussed.	Awareness of AR
[12]	Elsevier	2021	Analysis of the application of AR in education and its requirements. Study on how content type affects the learning outcome.	Application Requirements
[3]	MPDI	2021	Overview of AR technology application in education from the first application in 1995 till nowadays. Definition of three generations of AR in education: Hardware-based, Application-based, and Smart glasses/Web-based.	Advancements of AR
[25]	Accents	2020	Potentials and benefits of AR in education. AR allows learners to interact with virtual 3D objects and offers a better user experience. A review of educational applications that are based on AR technology is presented.	Benefits of using AR
[20]	MPDI	2019	Degree of diffusion of AR and teachers' opinions about the need for continuous training. Feasibility of AR application development by teachers and students in school settings.	Conditions for the feasibility of AR
[7]	IEEE	2018	Current trends and scientific findings in AR, its applications, and uses in teaching, learning, and training. Several AR software are listed, along with recommendations.	Latest Trends and Scientific Findings in AR
[23]	Taylor & Francis	2018	Impact of marker-based AR and marker-less AR on users. An experimental design is discussed to compare the two different optical tracking systems of AR. Both methods allow users to visualize the features virtually, but markerless AR is recommended.	AR types
[9]	Elsevier	2017	AR can support learning and teaching. AR offers unique advantages, but challenges such as, pedagogical and technical issues must be addressed.	AR Advantages, Disadvantages, and Challenges
[27]	ERIC	2016	A meta-analysis of AR applications in education. AR positively affects students, providing an enjoyable game medium, increasing imagination and creativity, and showing astronomical events and dangerous experiments. AR positively affects students and is a technology with high efficiency in education.	Efficiency of AR on students and educational applications
[47]	Dialnet	2014	Analysis on how AR influences academic performance and encourages student motivation. AR technology improved academic performance and motivation in 25 mechanical engineering students. Significant statistical differences between their academic performances resulted, proving to be higher in the experimental group using AR with a higher motivation level.	Impact of AR on academic performance
[13]	DUGiDocs	2014	A literature review on AR in educational settings considering: uses, advantages, limitations, challenges, and features. AR is found to be a promising technology for supporting education.	Advantages, Limitations, and Challenges of AR
[17]	Springer	2014	Analysis of 26 articles related to the integration of AR in education and a comparison of AR-based learning with non-AR learning. A heuristic questionnaire was used to assess AR potential, including advantages and disadvantages.	Advantages and Disadvantages of AR
[22]	IEEE	2013	A marker-based tracking system that detects QR codes on camera capture and overlays rich media from a server is proposed. The performance was analyzed and found promising.	AR types
[57]	Elsevier	2013	A literature review on the effectiveness of merging AR techniques with smart devices such as smartphones or tablets and their promising potential for education.	Mobile Augmented Reality
[16]	Elsevier	2013	Development of three different AR learning environments to be used in classrooms. The environments are designed with the help of teachers. Essential features to be considered when targeting AR-based learning classrooms are proposed.	AR Essential Features

(Continued)

Table 3. Review of AR in education *(Continued)*

Ref.	Publisher	Year	Overview	Topic
[2]	Elsevier	2012	Introduction of AR as a technology and its applications in education. Different methods and key technologies are discussed.	AR Methods
[10]	Springer	2012	Description of AR and its application in education and training and its impact on the future of education.	Impact of AR on Education
[15]	IEEE	2012	Increasing awareness of educators on AR and how AR can positively affect the learning environment. Analysis of 32 articles to compare AR-based learning to non-AR applications.	Increase awareness of educators on AR
[19]	Springer	2009	Description on how students and teachers are using AR simulations and how it helps in teaching and learning. Qualitative case studies were conducted in the US and showed the effectiveness of this technology on the learning process and the limitations of AR simulations.	Effectiveness and limitations of AR

Table 4 classifies 41 analyzed articles based on the area of application. 14 different educational fields are reported, which are illustrated in Figure 3.

Table 4. Fields of AR applications in education

Ref.	Publisher	Year	Overview	Application
[43]	IEEE	2022	A survey on Extended Reality (XR) and its impact on education, specifically in the mathematical field. XR has a wide range of applications in education, allowing instructors to present real-world experiences to students.	Mathematics
[49]	Springer	2022	Effects of using QR codes to enhance student performance in Saudi education. Results showed a higher performance.	Science in Middle School
[59]	Elsevier	2022	Insights on AR applications in formal education. Benefits and implications of the use of AR that might improve the process of how AR should be integrated into educational settings is discussed.	Physical Education
[38]	MDPI	2022	A review about applying AR to support students with educational needs. The analyzed studies showed positive results in the learning process.	Special Needs
[28]	Elsevier	2021	A review on the validity and effectiveness of AR in surgical education. 24 studies were included to evaluate the use of AR as an educational tool and compare it to other simulation models. Results were encouraging.	Healthcare
[32]	Elsevier	2021	Development of AR-based applications for primary school students in order to investigate the effectiveness of AR-based learning in terms of performance, motivation, attitude, and behavior toward different methods of learning. Results showed a significant enhancement.	Primary School
[37]	Springer	2021	A study on the use of AR as a learning material in the education of special needs students. Results were positive and promising.	Special Needs
[39]	IOP	2021	Analysis of AR technologies when adapted to the teaching of natural and mathematical disciplines. The role of the STEM approach with AR in the educational process is determined. AR and STEM provide an opportunity to stimulate creativity, develop scientific and research skills, and implement current competence.	STEM
[6]	IJISRT	2021	Discussion of how AR is used in different learning areas. AR applied to education can lead to a smart campus.	Many fields of teaching: Languages, Science, Vocational training, etc.
[5]	Elsevier	2021	Use of Marker-based AR and application on electrical circuits. AR helps students acquire, process, and visualize information, making learning faster and more enjoyable. Educational institutions need to change their curriculum to follow a modern approach. AR is very helpful and effective in lab work.	Electrical Circuits

(Continued)

Table 4. Fields of AR applications in education *(Continued)*

Ref.	Publisher	Year	Overview	Application
[14]	IEEE	2021	The possibilities of using virtual and augmented reality devices such as Google Glass or Oculus Rift for individual teaching classes. Studies and reviews revealed better results for both students and instructors using this technology.	Teaching
[60]	Elsevier	2021	Investigation on how AR affects and improves the learning process in the Computer Science (CS) Education domain. The evolution of this technology, the challenges that can be faced, and the impact on learning outcomes are discussed. AR provides considerable results in facilitating CS learning.	Programming
[48]	Springer	2020	AR-based learning was used to evaluate and develop an AR-based application to teach electrical currents to fifth-grade students, with better results when students are working individually.	Electrical Circuits
[34]	IEEE	2020	Proposal of an AR application named Geo+ to support primary school students in the acquisition of knowledge on solid geometry. Geo+ is effective in terms of student learning. Students found it easy to use.	Geometry in Primary School
[50]	Taylor & Francis	2020	Experimental work based on assembling and exploring a modularized mobile robot task called Buzz-boards. 36 students participated in this study, and 18 were in both experimental and control groups. As a result, the pedagogical virtual machine (PVM) with AR was more efficient than a paper-based concept for learning achievement, fun, and usefulness.	Robotics
[54]	MDPI	2020	Assessment of the impact of AR in higher education. AR can increase class participation, student creativity, and motivation but requires initial training of teachers to take advantage of its benefits.	Higher Education
[40]	MDPI	2020	The use of Active Learning method for teaching STEAM subjects, using a format where students are tasked with building an AR application as part of their learning. Evaluation of the applicability of STEAM subjects with a qualitative case study approach.	STEAM
[36]	SAGE	2020	A study on the effectiveness of using AR while teaching mathematics to middle school students with a specific learning disability (SLD). Variables used to measure the effectiveness were the percentage of steps learners performed correctly to solve a problem and the AR video-based intervention. AR improved problem-solving skills in SLD students.	Mathematics and Special Needs
[45]	Elsevier	2020	Investigation on how AR can enhance student motivation towards learning and improve classroom interaction, specifically in engineering fields. The work was done through a questionnaire.	Engineering
[55]	Wiley	2020	The use of AR in vocational teaching. A case study of chemical industry training in Germany is discussed. AR has advantages for low-risk physical tasks leading to higher learning achievement and better learning performance.	Vocational Teaching
[58]	MDPI	2020	Impact of AR on educational activities and comparison to traditional learning methods. AR substantially impacts education, particularly in physical courses, and should be used more frequently.	Physical Education
[30]	Springer	2020	Visualization technology (Augmented reality instructional tool ARIT) to evaluate geography learners' performance and retention. As a result, the study showed that geography teaching could be enhanced using ARIT.	Geography
[29]	Elsevier	2019	The use of AR and its challenges related to healthcare education, such as teaching anatomy, performing training, and simulating emergencies.	Healthcare
[4]	Frontiers	2019	Analysis of 50 studies to highlight the potential improvements of AR on education. AR can potentially improve education for students with disabilities with high interest, motivation, and interaction.	Special Needs
[44]	MDPI	2019	A procedure to determine the degree of student motivation when utilizing notes enriched with AR in the classroom which they can access via mobile devices.	Science

(Continued)

Table 4. Fields of AR applications in education *(Continued)*

Ref.	Publisher	Year	Overview	Application
[1]	Springer	2019	Importance of AR-based learning material to study the multifaceted views of plants. Fifty-four third-grade students were tested in the plant observation activity. AR-based learning enhanced the learning experience for third-grade students with a higher comprehensive level than traditional learning.	Chemistry
[35]	Elsevier	2019	A mobile augmented reality application developed to address the needs of students with special needs, providing a new way of teaching geometry and enhancing the learning environment.	Geometry and Special Needs
[18]	Elsevier	2018	A literature review on the use of AR in favor of STEM. According to the results, the AR-based STEM learning applications reviewed were evenly distributed among physics, math, and life sciences.	STEM
[11]	IEEE	2018	Summary of the newest trends in education concerning the requirements of Industry 4.0 (one option is AR). AR facilitates teachers' work since the information is available in real-time on their own devices, which will improve students' autonomy.	Industrial Automation
[53]	Springer	2018	Development and use of AR as an educational tool. AR devices can be divided into wearables, handhelds, and fixed screens. It also explains learning theories that help teachers integrate AR into education.	Training and Informal Learning
[56]	Modestum	2016	Proposal of an AR model for school physical education based on different technologies such as cloud network, Internet of things, and remote users. The outcomes of using AR were promising and increased positive learning ability with a better performance in students' engagement in sports.	Formal Education
[26]	University of Alicante	2016	Highlights of several critical factors when combining AR and education. Numerous examples of where AR practices were used and to what level of education. Instances of the differences between AR and VR are also provided.	Game Base Learning
[51]	IEEE	2016	Discussion of TeachAR, which is better than traditional teaching methods for teaching basic English words to kids with non-native language, leading to better learning outcomes.	English
[33]	Modestum	2016	Teaching kindergarten children the English alphabet using AR apps and traditional methods. Significant differences in interaction and test scores resulted, highlighting the importance of integrating AR into education.	English
[42]	Elsevier	2015	A study on 45 grade-8 students engaged in a frame lab. Students can develop a molecular-level explanation of macroscopic phenomena when physical and virtual experiences are combined into an augmented virtual sciences lab. The results showed that students could better develop molecular-level explanations for gas behavior and refine alternative ideas related to the concept when using AR.	Science
[24]	IEEE	2015	A study on how meaningful activities affect student behavior and learning performance. AR-based simulation tools for teaching basic principles of electricity to ninth-grade students are presented. As a result, AR was found to have a good impact on learning outcomes.	Physics
[21]	Taylor & Francis	2015	A literature review on the use of mobile game-based AR and its effect on education in the context of formal and informal environments. The study demonstrates that AR improved scientific argumentation and communication skills.	Formal and Informal Learning
[41]	Elsevier	2014	Testing AR-based learning to teach chemistry to high school students in China. Students could conduct some experiments and interact with 3D models of micro-particles using markers. AR-based learning had significant learning effects, especially for low-achieving students.	Chemistry
[46]	Elsevier	2013	A study on the use of AR and its impact on the motivation of middle-school students. Four motivational factors are considered: attention, relevance, confidence, and satisfaction. AR-based learning has a better outcome than slides-based learning, with students showing interest and confidence.	Middle School
[31]	ACM	2011	A study conducted on children using body-based metaphors which can challenge their intuition and allow the learner to be part of the simulation. Children's interaction using AR is higher than traditional learning, providing a deeper understanding of the material.	Astronomy

5.2 Limitations

As discussed earlier, AR technology could enhance the educational sector. With AR tools integrated, the content of a course or activity can be visualized during the learning process and thus leading to a more interactive, motivational, and enjoyable environment. Studies showed that students perform better with AR-based learning than with traditional methods. However, some limitations need to be highlighted here. The readiness of teachers to use such technologies is essential during the learning process. During the implementation phase, training teachers to deal with this technology and be comfortable using smart devices is also essential. Limited screen size, difficulty in designing and developing instructional materials, and prohibitive costs are other limitations in this context. Before considering the adoption of AR in every educational aspect, more investigation and validation are needed since the student sample size used by most researchers to validate their systems is limited. In addition, more studies in the literature need to be available to analyze the characteristics and consequences of AR deployment in this sector. The limitation of the curriculum and the need for educational applications with good learning content is also considered limiting factor during integration. The existence of good internet connections in educational centers and the flexibility of the design and its adaptation to the content are other limitations. The course topic and grade level may also affect how learning is delivered with AR. Table 5 lists the limitations and potential solutions that can be used in future case studies.

Table 5. AR limitations and potential solutions

Limitation	Potential Solution
Accessibility, usability, dissemination, and pedagogical approaches.	Updating the curriculum and testing new approaches.
Teacher's readiness to implement these technologies.	Performing training in the use of technology for teachers, thus having experienced teachers.
Dependence on hardware and content portability issues.	Provide smart devices and ensure a well-equipped environment.
Curricula are already overloaded, and schools need more developmental resources. Lack of educational applications with good learning content.	Updating and developing curricula that focus on the quality of teaching and not the quantity.
Limiting screen size, difficulty in designing and developing instructional materials, and prohibitive costs.	Updating and developing curricula that integrate AR while taking into consideration the technology used in a way to reduce the time spent.
Lousy internet connection in the education centers.	Creating a well-maintained infrastructure to have a good internet connection.
Lack of studies on the use of AR applications in the education of the disabled.	Focusing on this field in future studies to consider AR in improving the education of students with disabilities.

6 FUTURE WORK

As a future work, the authors will focus on increasing the awareness of using AR in education. Many schools located in Lebanon will be visited to highlight the importance of adopting such technology. Studies and surveys will also be conducted

to show the increase in students' motivation, understanding level, and engagement inside classrooms. Student's grades will be analyzed based on AR-integrated assessments vs. the traditional learning methods.

7 PAPER CONTRIBUTION

Considering the validity and effectiveness of adopting AR technology in education, this paper's contribution summarizes as follows:

- Increase awareness of using AR technology.
- Highlight the importance of deploying AR in the educational sector.
- List the advantages, disadvantages, and limitations of AR with potential solutions.
- Discuss the latest developments in HW and SW.

Figure 3 illustrates the different fields of education where AR techniques are integrated and covered in this work.

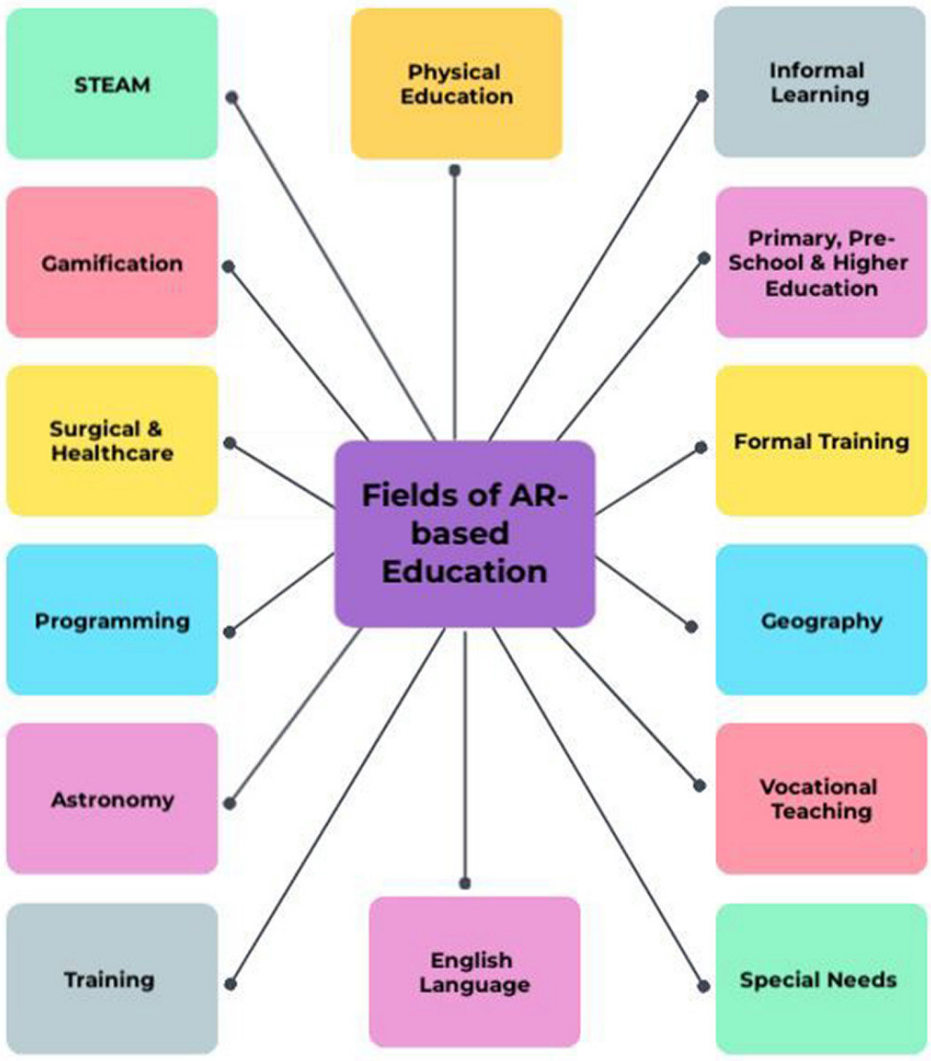

Fig. 3. Fields of AR-based education

8 CONCLUSION

With the massive spread of technologies nowadays and the surge of enhancing the educational sector quickly, several types of technologies can be adopted. Augmented reality, in particular, is validated to be a very efficient tool in ensuring the engagement and participation of the users, either students or teachers, in the learning process. Results of AR adoption in education show a significant enhancement in learning outcomes. Students are more engaged and motivated, and thus a better understanding level is achieved. More specifically, AR applications help students create new learning experiences, improve student performance, boost their critical and analytical thinking and problem-solving skills, increase cooperation in-group work, gain new skills, and even boost student-tutor interaction. Moreover, studies showed a positive attitude from teachers who could reduce their workload and deliver better outcomes. However, some limitations arise and need to be addressed, such as ensuring that users are aware of this technology and how to use it, providing training for both parties, ensuring a well-equipped environment, and many more. AR technology allows users to immerse into the virtual world by projecting virtual data onto the real world. However, the content type used in AR applications must be clarified. Most researchers claim that there is no predefined method or preferred design to develop AR content. Most applications depend on the developer's experience and point of view.

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