The Importance of Augmented Reality Technology in Science Education: A Scoping Review

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***Abstract*—The use of digital technology such as augmented reality AR technology has been an important topic of research in several fields, uncovering diverse benefits regarding its impacts. Although there have been numerous empirical studies on the design and evaluation techniques of the AR approach to enhance physical, cognitive, personal, social abilities in science education, their outcomes varied in different science disciplines, and there is a lack of reviews on how the AR has been applied in the field of science education. The aim of this study is to conduct a scoping review on the positivity of AR applications in science education. This study presents a scoping literature review of 26 studies published between 2015-2020 on AR in science education. The results indicated an overall positive impact of AR in science education. The results from this systematic review are expected to provide valuable information regarding the AR usage in science fields.**

***Index Terms*—Science education, augmented reality, scoping review, education.**

I. Introduction

The study of science is a process that involves several complexities relating to problem identification, problem investigation, hypotheses formulation, data collection method planning, hypotheses testing, data collection, obtaining results and making conclusions [1], [2]. The students' participation in the above processes could lead to enhanced critical thinking in every step-in order to reach the best outcome [1]. Owing to the common belief among students that Science subjects are difficult, only a few of them opt to embark on the science field, with some ending up facing study issues like disengagement and negative attitudes towards science education [3]. This may be attributed to the education inculcation approach that falls short in satisfying the demands of time [4]. Although the currently employed teaching approaches have been evidenced to enhance students' learning outcomes, researchers found that enhancement of such learning in science courses remain mixed and inconclusive, particularly when it comes to the top effective interventions [5], [6]. In relation to this, researchers [7], [8] have connected instructional practice (e.g., teaching and learning technology) to the students' successes.

Additionally, technological developments have led to the extension of the boundaries of both teaching and learning and the development of courses delivery models (e.g., e-learning, video recording methods, computer-assisted teaching and multi-sensory based teaching) [5], [9]. This type of technology has generated top attraction particularly virtual reality, e-learning, flipped learning and augmented reality, all of which research has been attentive of [6], [7], [10], [11]. In the world of learning, augmented reality (AR) is considered to be of valuable contribution towards teaching and learning, while at the same time enhancing successful achievements of students [7], [8]. In the context of science courses teaching, using visualization techniques like AR and 3D materials, actual real-life objectives, videos as well as other technology-assisted approaches help learners to understand abstract and invisible concepts [12].

More specifically, augmented reality (AR) combines and superimposes information, virtual and real-world objects [13]. AR also delimits learning in light of senses, in a way that it caters to all the senses, namely, hearing, smell, touch and sight [13], facilitating educational inclusion processes [14]. AR is represented through different action means and processes of students' learning engagement [15] and the related system includes features into the instructors' lecture notes [16], concretely inculcating abstract information to the students. According to [17], AR allows the events that are not easily observed in real life to be observed and thus, it is valuable to education due to its facilitation of an extended combination of learning environment that boosts critical thinking, problem-solving and cooperative communicative skills among students using both physical and digital materials in a single environment [16], [18].

In the current times, students' interaction and engagement with animated objects have been transformed by AR using topics visualization and understanding of actual circumstances and real-life issues [19]. Based on the AR technology studies, AR is able to promote teaching and learning results in terms of attitude, confidence, interest, motivation, spatial ability, engagement, achievement and eventually, the students' satisfaction [18], [20]. Evidence from literature shows that AR technology application is capable of enhancing learning experiences and learning activities [21] and although such teaching approaches are clearly invaluable, studies dedicated to them are still lacking as existing systematic review was conducted based on studies published between 1988-2014 [6], another study was also

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limited om teaching mathematics to secondary students with disabilities [5]. Therefore, more studies are needed to examine the AR effectiveness in learning science courses in order to establish a systematic literature review on technology use in education fields [20], [22] Such systematic reviews are lacking despite their need to determine AR trends effectiveness, particularly in science education. Thus, in the present study, literature on knowledge-based AR interventions is explored through the analysis of studies in science education using different databases.

II. Literature Review

A. Augmented Reality

Augmented reality (AR) is a general term used to cover a general expansive technology range that projects computer generated contexts in the form of text, images and videos into perceptions of the real world [21]. In this technology type, the physical and the virtual world are combined to enhance the user's environment and is reinforced by information using camera-produced images, videos and audio, using mobile computer technologies [23]. In a related study, [21] provided an extensive explanation and discussion of AR technology and its applications, whereas [24] explained that AR technology in the education field has become viable in the current period as new applications that operate on computers and mobile devices have lessened their prices in comparison to their preceding technologies that required sophisticated equipment (e.g., head-mounted displays). The integration of both real and virtual objects in AR allows the user to visualize abstract concepts and complex spatial relationships to enable phenomenon experience like never before, supporting the user's interests towards learning [17]. AR applications are of several types including AR books, AR gaming, discovery-based learning, object modeling and skills training [21].

Specifically, in AR books, there is a combination between digital content and physical content through physical book augmentation with 3D objects, voice and multimedia elements, allowing for the minimization of the virtual-physical realm gap [25], [21]. AR books enable learners to experience various feelings of touch, smell, taste, sight and hearing [25], in such a way that they interact with the content supported by information, which physical books can never provide.

B. Purpose of the Study

Literature generally focused on the determinant factors of AR application in science courses, with studies presenting an extensive review of AR factors remaining few and far between. In this regard, this study conducts a systematic literature review to identify the impact of AR status in the field of science education. It also examines categories of analysis for this purpose as well as AR tendencies, advantages, limitations, and effectiveness in the same context. The study also examines its availability, adaptation, and personalization in light of its applications. The analysis of the different categories would stress on the emerging trends, opportunities, challenges and literature extension and visions towards the objectives and outcomes of its future usage. AR application in science education is investigated on the basis of the following research questions.

1) What are the skills achieved through AR use in science education?
2) What AR applications are used in science education?
3) What are the pedagogical strategies being integrated with AR application in science education?
4) What are the science education fields in which AR technology is used the most?
5) What are the advantages and challenges related to AR in science studies?

III. Method

In this study, a 4-phased process of systematic review of relevant studies was adopted from PRISMA model [26], [27] which are identifying the research questions, identifying relevant studies, study selection and summarizing and supporting the results. First step, identifying research questions which are, 1) What are the skills achieved through AR use in science education? 2) What AR applications are used in science education? 3) What are the pedagogical strategies being integrated with AR application in science education? 4) What are the science education fields in which AR technology is used the most? and 5) What are the advantages and challenges related with AR in science education? The second phase focused on identifying related studies dedicated to science education e.g., [28], [29]. Study selection was performed through some criteria's [26], [27] for excluding and including studies for the studies published between 2015-2020. The criteria included journal type, methods, research topics, data analysis, findings, limitations, advantages and disadvantages of AR and conclusions. The study conducted an extensive and thorough systematic review to determine AR studies trends in science education, by examining articles from ScienceDirect, Scopus, Elsevier and ISI. 'Augmented Reality' was the key word used searching the above databases. Using augmented reality as a keyword, 47 studies are selected to be reviewed. A review of the studies revealed that some studies are irrelevant, particularly those related to unknown samples, study focus and AR features. Twenty-six studies were selected from the databases and were deemed appropriate for the objectives of the study on the basis of the assessments of clear outcomes, technology descriptions, number of individuals reports, and presentation of variables, statistics and outcomes. The studies were detailed and divided based on the name of the author, grade level, variables, results and study findings as shown in Table I.

TABLE I: Studies Included Following prisma Model

Study Recorded 2015-2020	Excluded Studies	Final Number of Studies
47	10	26
Studies Included	Excluded Studies (Not from the study databases and samples not fit)	
37	11	

IV. Results

The present study addressed several questions, the first of which was: "what skills are obtained through the use of AR in science education? Based on the result, AR technology enhanced various learning skills among science students, including their learning outcomes and their personal and cognitive skills. The result indicates 18 academic skills commonly mentioned in majority of the articles (69.32%). As for the enhancement of personal skills, 7 studies (26.92%) found AR to contribute towards it. A single study was found to examine the social skills enhancement of students through AR (3.84%) wherein AR technology facilitated interaction and collaborative inquiry learning among students and enabled them to extensively examine the inquiry process [30]. The second question of the study pertains to the AR applications used in science studies. Several applications have been reported to be used in these studies like zSpace, AROSE, AR, AR marker, ARToolkit, 2D image-based AR-VR, 3D AR-VR model and 4D model, mAR application and AR book application. Overall, there is consensus among these studies that AR implementation in science education requires multi-AR applications, showcasing its flexibility and its usefulness in any place, paired with other devices and equipment's. This is exemplified by [31] who revealed that Marker-based AR technology can be easily developed and used, whereas other studies like [32] reported that some applications are more opted for by technicians owing to their technical skills and that they can be used internal and external to classrooms.

The third research question that guided the present study concerns the pedagogical strategies integrated with AR technology in science education. Although, few studies integrated AR determined the pedagogical strategy, Table II showed that some studies integrated AR technology as game-based learning (2 studies, 7.70%), inquiry-based learning (5 studies, 19.30%), learning tool comparison (17 studies, 65.30%), and image-based learning (2 studies, 7.70%).

As for the fourth research question, the results showed that AR technology were used the most in general science education studies (42.30%), followed by biology (15.40%), chemistry (15.40%),) and anatomy (11.53%),), followed by STEM (7.65%) and physics (7.65%). The fifth question addresses the advantages, limitations, and challenges of AR reported in science education studies. It has been found that the use of AR in the field of science education enhances students learning skills, promotes self-independence and learning engagement [33], enhances knowledge of science vocabulary [34], general learning enhancement and flexibility in usage. It is an attractive technology that is useful for many medium desktops, mobile devices and smart phones [35], which all contributes to easy and fun learning and understanding. Advantages of AR were also investigated by [20], who stated that educators are enabled to carry out their experiments with the help of AR applications to reinforce learning of students. This was also reported by [1]. The authors revealed the capability of AR in mitigating the misinformation that arise because of the students' inability to encapsulate concepts relating to science topics as AR enables in-depth visualization and object animation for better subject understanding [1]. Aside from the above studies, [36], [37] showed that AR improves the students' learning motivation, their positive interest, behaviors and learning outcomes, along with their visual spatial abilities and skills [18], [38], [39].

With regards to the AR technology challenges, results in Table III showed that the majority of the studies e.g., [29], [40]-[42] agreed that its activity design and technology limitations are the top and this may be due to the relation of the activities to the specialized devices and the required realities to be presented [29]. According to [35], academic settings mostly lack AR tools because of minimal financial support and lack of awareness concerning its needs in the same setting, with several applications to be kept into account. Similarly, [43] and [17] highlighted the need for the integration of AR systems into other hardware and software devices, enabling interfacing issues between them and stable flow and running of system to arise.

Another major challenge is logistics, where owing to the limited resources and the far locations, issues also arise; for instance, [43] mentioned that AR should be designed in a way that it relates to real-world location and its features to real contexts. AR features were also revealed to be another challenge [44] and this may be resolved through the provision of user support and the development of effective and appropriate design in the learning surroundings. AR designers should take this gap into consideration to support instructors and students teaching and learning processes.

TABLE II: A Summary of the Sample Used in AR for Science Education

Authors	Results	AR features	Pedagogical strategy	Fields
[40] Petrov 2020	Improve students learning experiences	zSpace platform image	Learning tool comparison	STEM
[29] Badilla-Quintana 2020	Improve students' achievement and students social cognitive	AR molecules editor App	Learning tool comparison	Chemistry
[45] Cai *et al*. 2021	Enhance student's self-efficacy, understand concept and cognitive skills	AROSE	Learning tool comparison	Physics
[46] Chandike 2016	Improve students' performance, interest and their understanding	AR toolkit	Learning tool comparison	Biology
[47] Ewais & Troyer 2019	Enhance positive attitudes in the learning process	AR app	Learning tool comparison	Chemistry
[48] Hsu *et al*. 2019	Evoke students' interest and enhance their motivation and engagement	AR app	Learning tool comparison	STEM
[49] Zhou *et al*. 2020	Help students in their learning process	Unity 3D Textbook based	Inquiry based learning	Biology

[50] Alenezi 2019	Improve students' motivation and performance	4D AR app	Learning tool comparison	Biology
[51] Tomara & Gouscos 2019	Improve students experiences and their knowledge	AR app	Learning tool comparison	Science
[18] Weng *et al*. 2020	Enhance students learning	AR print-book	Learning tool comparison	Biology
[52] Cetin & Turkan 2021	Increase students' achievement and positive attitudes	AR based image	Learning tool comparison	Science
[44] Sahin & Yilmaz 2020	Increase achievement and positive attitudes	AR app	Learning tool comparison	Science
[53] Cheng 2018	Increase motivation and positive attitudes	AR image book-based	Learning tool comparison	Science
[54] Cheng 2018	Increase learning science achievement and perception	AR app	Learning tool comparison	Science
[55] Crandall 2015	Improve students' experiences	ARIS	AR Game-based learning	Chemistry
[56] Gnanasegaram *et al*. 2020	improve students' knowledge, motivation and engagement	3D holographic technology	Web-based module learning	Anatomy
[57] Habig 2020	Improve ability to solve problem and positive attitudes	2D ball-and-stick	Inquiry based learning	Chemistry
[58] Kurniawan *et al*. 2018	Help students learning easily	AR mobile app	AR Game-based learning	Anatomy
[59] Thees *et al*. 2020	Insignificant in improve concept knowledge and lower cognitive load	AR app	Learning tool comparison	Physics
[60] Ferrer-Torregrosa *et al*. 2015	Improve attention, motivation and written skills	3D app	Inquiry based learning	Anatomy
[61] Astuti & Masykuri 2019	Improve problem solving, motivation and learning outcomes	AR media	Learning tool comparison	Science
[62] Sirakaya & Cakmak 2018	Promote positive attitudes	AR app	Learning tool comparison	Science
[24] Akcayir *et al*. 2016	Improve students' skills and attitude	3D AR image-based	Learning tool comparison	Science
[42] Cheng 2017	Increase students' motivation and interaction	CLSAR AR app	Learning tool comparison	Science
[39] Liou *et al*. 2017	Improve students learning experiences	AR image-based	Learning tool comparison	Science
[63] Yildirim & Kapucu 2021	Increase academic achievement and knowledge	AR Space 4D application	Learning tool comparison	General science education

TABLE III: ADVANTAGES AND DISADVANTAGES OUTLINED

Study Number	Advantage	Study Number	Disadvantage
53, 56	Improve social skills	40, 55, 48, 53, 48, 53,	Logistics, activity's purpose and time period, and applications prices
49, 52, 24,	Improve personal skills	47, 50, 51, 52, 57,	Skills and abilities of the users and sample size
40, 29, 36, 55, 47, 48, 50, 51, 18, 44, 54, 57, 58, 59, 61, 62, 42,	Improve learning and cognitive skills	36, 29, 53, 54, 63	Technology limitations

V. DISCUSSION

The result of this study supports the effectiveness of AR in enhancing science learning among students and this may be attributed to the use of scientific learning procedures in AR that facilitates optimum achievement and understanding of the abstract concepts in the field [44], [64]. Science subjects contain complicated procedures and processes that are challenging to visualize, imagine and comprehend and thus, AR technology extracts such contents, making them more comprehensible.

In fact, prior literature e.g., [29]-[44] made it evident that AR is a frequently utilized tool in science learning and is one of the current technologies that has top potential to be included into learning, providing greater information that extends knowledge access [29]. AR represents the combination of digital information with physical information in real time for the benefit of the user. Moreover, AR has been described as providing technology enriched extensive topics information from both real and virtual realms [29], [64], [65]. Literature also supports the effective AR application usage in facilitating learning process and enhancing academic outcomes e.g., [40], [66]. It can therefore be stated that AR technology contributes to the significant enhancement of the effectiveness of education [65]. The number of studies that supported its contribution to cognitive skills was 9 (34.61) and was second rank to the most common AR contribution. This may be related to the fact that AR technology is attractive to students as it piques their interests, motivates them and encourages their interaction in the materials, making them pro-active during the sessions, and helping them understand the content to achieve successful outcomes [44], [61], [67]. Moreover, in [63] study, the author found learners to experience smooth knowledge-transfer when using media technology and the same goes for knowledge-sharing among students. They indicated that multiple media functions in the learning process could improve the learners' long-term memory for information and knowledge storage.

Similarly, students are motivated when using AR as their pedagogical activity is developed through the immersive technologies and their engagement heightens with the learning processes as explained in [29] study. The authors also stated that AR technology is helpful in making the students think and act in novel ways that could lead them to

collaborate and to engage critically during their learning processes. This may also be due to the enabling of AR tool to combines real and virtual examination of objects which presents immediate information to the students regarding the topics. In the same line of study, [68] found information that are immediate and relevant to be presented to the students using AR to facilitate their processing skills, their motivation and their comprehension of the activities. Based on the table, AR has been successful in improving the cognitive skills and social relationships of the students and in increasing their motivation e.g., [45], [55]. This may be connected to the benefit obtained by the students from AR tool in a way that it improves their view of technology in their learning environments, which means that AR is a powerful and effective technology in providing science education and in enhancing the students' learning and their cognitive skills [69]. Students in the AR group was found to outscore those in the Flash group in [45] study, in light of their conceptual understanding, higher-order cognitive skills, practical work and social communications. Conceptual understanding enhancement is logical as AR does affect the cognitive skills of the students [41], and their understanding of the topic [58].

The results also found a positive AR effect on the personal skills of students are few and far between e.g., [47], but prior studies also supported the positive effect of AR on skills, attitudes, and motivations e.g., [32], [45]. More specifically, [32] revealed that AR technology's provision of information is timely and relevant, to guide the learning of students and to boost their motivation, while [39] examined self-efficacy through their developed and implemented probability and statistics lessons using tablet-based AR among students in middle schools. Their findings showed that student's self-efficacy is enhanced leading to heightened attention to conceptions and application of advanced strategies in their probability and statistics courses. Also, in [34] study, the authors illustrated the AR effectiveness in supporting individual's decision-making, autonomy and learning control [7]. They reaped the benefits from AR technology in terms of teaching materials that enriched their education and piques their interests, allowing for the development of their perspectives concerning the real world.

The results of this study also found that AR enhanced students' social skills through interaction which enables them to focus on and share objects and ideas with their peers, while providing the way for activities (practice and interaction) during their processes of learning. AR was evidenced for being appropriate and useful to students as it provides actual experiences to them while enhancing their social interaction and collaboration in the learning environment [8].

The second question showed that several AR tools were used in science education. However, the objective of AR usage was to boost the students' motivation, explain topics to them and enhance their learning experiences and engagement in their activities by making use of the AR features. Many of the teaching-learning sessions were based on practical instruction and hence, computer-assisted instruction is an effective method that can be helpful to enhance students learning experiences.

Results of question three showed that there are limited pedagogical strategies used in integrating AR technology in science education such as inquiry-based learning, image-based learning and game-based learning. The result may be due to the fact AR is still an emerging technology in science education and more investigations on how to implement it are needed. Results of question four showed that general science education used AR the most compared to other science disciplines. This may be due to the fact that AR technology can be a novel and accessible tool to specific science domain but not to all as every science domain has its own characteristics and needs. Thus, general science domain used it the most as it has the basic knowledge and conception compared to specific domains such as chemistry, biology and physics.

Regarding questions five, results showed positive advantages of using AR in science education which can be linked to the general premise that technology, with the inclusion of AR, responds effectively to science students [44]. Furthermore, AR plays a key role in improving the social skills and interaction among students and their motivation e.g., [55] and this may be explained by the social environment found in schools and universities that reinforce social interactions, facilitating the leveraging of advantages that AR tools provide. In addition, peer and teacher interactions at its best motivate the students, maximize their engagement, and improve the development of their non-targeted skills as mentioned by [55]. Other authors [36], [51], [56] also showed how AR facilitate social skills in learning and application and social interaction qualitatively and quantitatively, indicating that AR is a major tool in bringing about learning and skills development among students. Finally, AR encourages the students to hone their personal skills, social relationships, and motivation [36], [56], [51]. On the other hand, several limitations of AR usage were highlighted, include the need to develop AR based on the students' abilities as opposed to their perceived needs. According to [24], students may be totally dependent on AR technology that they will refrain from studying outside the classrooms, and they may focus on the AR components themselves rather than the topic being learned. However, the novelty of AR makes it operations and full potential in the dark, and whether or not objects for interventions can enhance its efficiency and effectiveness. Limitations also originate from the activities purpose and time-period. AR applications have to be developed based on the users' perceptions and needs, particularly in terms of the information provided. AR limitations mentioned were also linked to the skills and abilities of the users, and this is understandable considering the fact that this technology has just begun. Finally, technology limitations were also reported in the related studies such as design activities and the availability of the internet.

VI. Conclusion

The extensive use of AR only began in the last few decades in providing science information and curricula to science students. In this study, the focus is laid on the effectiveness of AR on the learning outcomes of students in science courses. The study carried out a systematic review to determine the use of AR technology from the perspective of students,

highlighting the strengths and weaknesses of several approaches, and providing data to comprehend the way AR can minimize the different limitations and challenges that student of science courses face when it comes to using AR. The literature review on the use of AR applications showed a total of 35 implementations with the studies agreeing on the positive role of AR technology in science courses on different skills (personal, emotional, cognitive and academic skills) and at all levels (primary, secondary and university level students).

VII. Limitations and Suggestions

The present study is not without limitations. First, the majority of the studies reviewed did not examine the influence of students' characteristics, which needs to be investigated in future studies. Furthermore, most of them used small-sized samples of participants, and thus, future studies should consider bigger sized samples to validate the findings. Another limitation relates to data collection methods, which future studies should consider, so that they can adopt other approaches. This systematic review presented information concerning ideas and solutions as to how science achievement among students can be improved through AR technologies usage.

Conflict of Interest

The authors declare no conflict of interest".

Author Contributions

All the researchers contributed to the paper. Dr. Malek, Dr. Ashraf, Dr. Ayat, Dr. Wafa conducted the research and its literature and shared the writing of the manuscript of the paper and made the final compilation; Dr. Mohamed and Dr. Belal analyzed the data as well as check the whole one; Dr. Ahmed and Dr. Ahmed wrote the discussion, reviewed the paper and had approved the final verion.

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