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*Review Article*

# Effects of Augmented Reality in Primary Education: A Literature Review

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Augmented reality can provide an interactive learning environment. This leads to an exploration of new possibilities in the educational domain. In this work, a systematic literature review of AR applications developed for preschool and primary education is presented. To conduct this review, the Google Scholar database was used. The articles were screened using a set of five inclusion-exclusion criteria for suitability. In total, seventy-one articles published between 2012 to 2021 were selected. Of those, forty-five are conference papers, one is a book chapter, and the remaining twenty-five are journals. These works were analyzed by nine research questions proposed by us. We identified enjoyment, engagement, and learning gains as the key achievements of AR-based applications. Besides this, improvement in motivation, learning interest, participation, understanding, and self-learning are also found important in our review. Although, there are challenges—usability issues, technical problems, acceptance, cognitive overload, and health issues; however, due to their numerous benefits, AR-based applications may be another mode of teaching-learning method in the near future.

## 1. Introduction

With the improvement in ICT (information and communication technology), augmented reality- (AR-) based applications have been gaining popularity over the last twenty years. AR superimposes 3-dimensional objects into the real-time environment. Therefore, it can simulate real-world scenes [1]. This in turn can help to improve users' perceptions as reported by Azuma [2]. AR technology seamlessly adds digital content to the real world [3]. It uses computer vision, image processing, Internet of Things (IoT), human-computer interaction (HCI), and computer graphics techniques to smoothly integrate digital content with the physical world [4]. Currently, AR is used in several areas—medical, military, advertising, maintenance, construction, sports, entertainment, tourism, architecture, and manufacturing [2, 5]. Except for the above-mentioned areas, AR is also gaining popularity for enhancing teaching-learning. AR applications are progressively recognized by different educational institutes [6]. Over the last twenty years, many researchers have developed AR-based learning applications and games suitable for different portable devices—mobiles, tablets, and laptops.

Traditional teaching-learning methods use chalk and talk approach, textbooks, posters, noninteractive video, and audio lectures. Online interactive methods, notably online video, require huge network bandwidth. Additionally, noninteractive method—textbook—may not provide extreme clarity of concepts for attracting students' attention and anticipating them to learn with utmost interest [7]. On the contrary, AR pedagogy can be regarded as a next-generation refinement of traditional teaching methods [8]. AR technology can alter conventional pedagogy to enhance learning outcomes [9]. AR-based applications can motivate students and improve their perception of knowledge. It can enhance students' learning with multimedia images, 3D objects, and animations. Additionally, students can interact with these AR-based applications while learning. This type of interactive learning environment is generally advantageous to students when it comes to comprehension and avoiding misunderstandings. In other words, AR-based interactive experiences help to visualize complex spatial relationships, abstract concepts, and chemical reactions [7, 10]. In addition to the various learning advantages, AR also motivates students and piques their attention, which is more effective than a traditional teaching strategy [9].

Primary or elementary education is made compulsory as a fundamental right for children all over the world (https://www.epw.in/journal/2006/35/special-articles/primary-education-fundamental-right.html). Preschool and primary school (PPS) education is a very important and crucial phase for children's mental development. However, providing education to students of this age has often become challenging. This may be due to the introduction of new things—alphabets, words, numbers, sentences, shapes, animals, vegetables, fruits, and more for the first time. It has been found that numerous children initially face problems in learning the alphabet. They frequently get confused and flip similar alphabets [11]. Wickramapala et al. [12] reported that students also struggle to identify between a wide variety of trees and animal species due to their lack of exposure to the natural environment [12]. However, with AR technology, we can provide them a glimpse of different fruits, vegetables, animals, or trees using 3D models and animations, which will allow them to view objects from all angles [12–15]. Due to the instability of their thoughts, young children have trouble memorizing the alphabet [13]. Therefore, the teaching approach for children needs to focus on creativity and engage them both in and out of the classroom. Hence, we can provide them with an AR platform where they can interact and learn about the alphabet or number system which is very crucial in their early learning. Helping them to better understand the letters and their corresponding sounds will help them in memorization and improve their pronunciation skills [13, 16]. We can employ marker-based AR technology to create a virtual 3D object to appear on their book or on any target images to attract them [17]. It has also been found that adopting AR applications increases the academic performance of students and also maintains high levels of motivation [18, 19]. As a result, an AR-based application can be incorporated into learning activities for young children since it boosts children's motivation, attention, and conceptual skills [20]. AR application can be an aid for the teaching communities. Teachers can use AR-based applications to teach different topics with multimedia images, cartoons, 3D objects, and exact pronunciation sounds rendered in the real world. In addition to that, AR applications can be used to teach any topic using any native language [13, 17, 21–26]. According to Motahar et al. [24], many parents lack the time and opportunity to teach their children and allow them for self-learning using tablets and smartphones. The coronavirus pandemic has also brought online digital learning as a core medium in almost all education sectors. Working from home, parents struggle to balance their work and monitor children's online classes simultaneously. Therefore, if working parents are unable to teach their children or uneducated parents are unable to help their children with studies at home, then parents must be encouraged to use technology like augmented reality (AR), which may be a suitable solution for simulating children's self-learning [12, 24, 27–29]. Increase motivation for self-learning has also been cited as a benefit of AR [30, 31]. AR applications can be operated on handheld devices without requiring any specialized equipment which makes learning possible anywhere and anytime.

With the rise of electronic devices, video games have increased in popularity and emerged as a potential learning approach. Mixing AR (augmented reality) and GBL (game-based learning), ARGBL (augmented reality game-based learning) applications provide the platform to engage users in a playful learning experience [32]. Children can learn better with the fusion of playing and learning at the same time. It also has positive impacts on children's learning [29]. Game-based learning encourages students' creativity by providing a competitive platform where they learn themselves by playing a game. It develops their strategic thinking capabilities and problem-solving skills. In addition to this, AR-based applications can also be used in inclusive education, where each child has the right to receive education according to their learning needs. These types of systems also take care of the need of differently abled students. AR-based applications can be designed for these types of special educational needs (SEN) kids as reported by Quintero et al. [33].

Some of the existing commercial-purpose AR tools available in market that can be used effectively in education are "AR 3D Animals" (https://play.google.com/store/apps/details?id=com.grappsgames.ortk_play.treedanimalsar), "AR animals" (https://play.google.com/store/apps/details?id=com.ARTEC.ARANIMALS), and "Animal Safari AR" (https://play.google.com/store/apps/details?id=io.lightup.safari). These AR applications are designed to educate students about animals and fish by bringing them to life in a semi-immersive environment. Children can also learn English alphabets and numbers with "LearnAR" (https://play.google.com/store/apps/details?id=com.augmenta.LearnAR) application, which also includes 3D models of animals, machines, and more. Additionally, "AR Study Ladder" (https://apkcombo.com/ar-study-ladder/com.dsinno.dsiar.studycard) helps users to learn English words and sentences to enrich their vocabularies. Last but not least, "AR anatomy" (https://play.google.com/store/apps/details?id=com.ARtec.ARAnatomy) is yet another AR tool that provides an anatomy experience.

Augmented reality is a promising field for enhancing education. While many researchers [34, 35] are currently working in this area, there are many prospective researchers in this field. It is always helpful for new researchers when systematic literature reviews are available at the starting phase of their work. We had a closer look at the literature reviews related to the use of AR in educational settings.

We examined the existing systematic literature review articles that used AR in educational contexts. These studies discussed different aspects of AR-based application, which encompasses both the lower and higher education sectors. To the best of our knowledge, no literature reviews of AR applications especially for PPS education with native languages have been reported. Therefore, to fill this research gap, we systematically reviewed the AR-based educational applications developed for PPS education. Our systematic review will shed light on the trends and current state of

AR applications in PPS education. This review will help the new researchers to know the existing work and expand the research in the future. A detailed analysis of the existing literature articles is presented in the next section.

## 2. Exploration of the Existing Literature Reviews

In this section, we briefly discussed some of the existing literature studies published in recent years that mainly focus on AR educational applications. Through literature evaluations, various perspectives of AR technology used in education have been investigated. It provides us with an overview of the previous effort, identifies any gaps that need to be addressed, and emphasises the necessity for further review studies.

Researchers have examined the tendencies of AR in educational settings to accentuate the current trends and techniques employed. It highlights the present state, the procedures used in the creation of AR applications, and the approaches used in their assessment. The study done by Sirakaya and Alsancak Sirakaya [35] reviewed the current trends of AR in education. One hundred and five articles were selected for this review. It was reported that the quantitative method was the most preferred research method, while the marker-based approach is used in the majority of the one hundred five articles. Further, it was noted that most of the articles use mobile device-based applications while undergraduate students were mostly used for empirical study. Bacca Acosta et al. [34] presented a systematic review of the current trends of AR applications used in education. They analyzed thirty-two articles published from 2003 to 2013. It was reported that there was an increment in the number of published studies of AR over the last four years. This study focused on and analyzed the different factors associated with AR-based applications. This includes uses, purposes, advantages, limitations, challenges, affordances, and effectiveness. It was also reported that the main advantages of using AR in education are learning gains and motivation toward digital study. However, maintaining superimposed information of AR-based applications was found difficult to deal with. It was also added that the future direction of AR would be the consideration of accessibility and usability issues. Masmuzidin and Aziz [36] studied the current trends of AR in early childhood education. The authors reviewed twenty-four articles about the existing works of AR from 2009 to 2018. They reported that the past ten years had increased the publication of AR studies for early childhood education. Their review identified some advantages of AR-based applications that include increasing achievement, enhancing motivation, positive attitudes and behavior development, enhancing social skills, and fun learning. They also reported that the empirical study was carried out with a minimum sample size of thirty or less and not more than two hundred participants.

Three systematic studies [37–39] which address the uses, benefits, challenges, and limitations of AR-based applications in education are also reported. Diegmann et al. [39] present the benefits of AR applications in educational environments after reviewing twenty-five articles. They identified fourteen benefits (identified as b1…b14) clustered into six groups (identified as G1…G6), as reported below:

(i) *G1 (improvement in state of mind)*: this group includes four benefits of our mind—increased motivation (b1), attention (b2), concentration (b3), and satisfaction (b4)

(ii) *G2 (improvement in teaching concepts)*: it includes two benefits of teaching with AR application—improvement in student-centric learning (b5) and collaborative learning (b6)

(iii) *G3 (improvement in presentation)*: three benefits in the presentation of learning content—increased details (b7), information accessibility (b8), and interactivity (b9) are reported in this group

(iv) *G4 (improvement in learning type)*: this includes two benefits of learning with AR application—improvement in the learning curve (b10) and creativity (b11)

(v) *G5 (improvement in content understanding)*: this group includes two benefits—improved development of spatial abilities (b12) and memory (b13)

(vi) *G6 (reduced cost)*: benefits of reducing cost (b14) is reported here

Out of the fourteen advantages, improvement in motivation (b2) and learning curve (b10) have a higher impact (more than 20%) than the others. They also reported the use of AR in possible directions for future work. Diegmann et al. [39] used five directions of AR in education by Yuen et al. [40] to further describe possible benefits in a different direction. This includes (i) discovery-based learning, (ii) modeling of objects, (iii) AR books, (iv) training of skills, and (v) AR gaming. It was further added that the causalities between the benefits and five directions of AR in the educational environment can also be a future topic of interest. Chen et al. [38] reviewed the use of AR in the educational domain. They analyzed fifty-five articles published between 2011 and 2016. The author considered the uses, advantages, features, and effectiveness of AR in the educational environment as the judgemental factors of their study. It was also reported that AR studies have significantly increased since 2013. They further added that most of the studies were reported on the science, social science, and engineering domain. After critically reviewing the fifty-five articles, it was concluded that AR was mostly applied in higher education studies. They further added that more studies need to be carried out considering the different cognitive processes and psychology immersion of AR with reality. Akçayır M. and Akçayır G. [37] present a systematic literature review of sixty-eight articles on using AR in the educational environment. Their study focused on factors such as publication year, learner type, advantages, and challenges of using AR applications in educational settings. The authors found an increment in AR studies in the last four years. Several advantages of AR which include learning achievement, motivation, positive attitude, enhancing enjoyment and engagement, and increasing communication and interactions were reported. They also identified a few challenges of AR applications—usability issues, cognitive overload, and technical problems. They concluded that AR technology might be useful in education when mobile devices and internet connections are available and the above-mentioned challenges are considered.

Researchers also have focused on analyzing the AR-based educational applications for STEM (science, technology, engineering, and mathematics) education. Sırakaya and Alsancak Sırakaya [41] reviewed the current status of AR in STEM education. They selected forty-two articles for the review and identified the advantages and challenges of using AR in STEM education. The advantages were reported in four categories: (a) contribution to the learner, (b) educational outcomes, (c) interaction, and (d) other advantages. On the other hand, the major challenges identified were the problems associated with marker detection, high content development time, and teacher resistance to AR applications. It was identified that most of the studies were carried out at schools (class or laboratory) and preferably conducted on K-12 students. They also suggested that further research on AR in STEM education can be carried out considering issues such as pedagogical approach and teaching techniques. Ibáñez and Delgado-Kloos [42] present a systematic literature review on using AR technology to support STEM education. They reviewed twenty-eight articles from 2010 to 2017 and claimed that the majority of the articles were published after 2013. The AR-based applications reviewed for STEM education were found evenly distributed among physics, mathematics, and life sciences topics. Learning outcomes such as motivation, attitude, enjoyment, and engagement are mostly reported. They suggested complementing the quantitative approach with the qualitative approach for a better understanding of AR-based STEM education [42].

Analysis of the AR-based language learning applications created to aid users in language acquisition was also presented. Parmaxi and Demetriou [43] reviewed the use of AR in language learning. A total of fifty-four articles published between 2014 and 2019 were selected for the review. This study identified the devices, software, empirical evidence, and benefits of using AR for language learning. They also identified the benefits and clustered them into four groups: (a) increment in motivation, satisfaction, attention, engagement, and enjoyment; (b) improvement in multiple language learning performances; (c) reinforcement of interactions; and (d) providing the opportunity for authentic language learning. In addition, they provided suggestions for future research which includes the development of a structural model and standardized methodology for evaluating the impact of AR experience. Fan et al. [44] present a systematic literature review of AR applications for early language learning. They reviewed fifty-three articles published between 2010 and 2019. Three types of AR learning activities, word spelling games, word knowledge activities, and location-based word activities, were identified. Further, they reported five main design strategies: (a) three-dimensional multimedia content, (b) hands-on interaction with physical learning materials, (c) gamification, (d) spatial mappings, and (e) location-based features. They also suggested two future research directions: understanding the learning effect of AR with various design strategies and investigating the generalization and maintenance of AR learning gains.

The usage of AR game-based learning (ARGBL) for educational purposes was also examined by researchers. Pellas et al. [45] highlighted the state of the art of ARGBL learning in both primary and secondary education. Twenty-one publications that were published between 2012 and 2017 were reviewed. They stated that the marker-based approach is the type of AR application that was most frequently employed in both primary and secondary education. When it came to usability tests, the research sample that was taken into account in numerous studies ranged from 30 to 200 participants, with mixed methods receiving the greatest consideration. Additionally, this study demonstrated that employing ARGBL in elementary and secondary education led to greater learning gains. In another study, Fotaris et al. [46] also presented a systematic review of ARGBL applications in primary education. They examined seventeen submissions spanning 2012 to 2017 for evaluation. This review study is aimed at providing useful recommendations to educators and instructors on how to enhance learning outcomes by integrating instructional paradigms into their teaching. The findings of this study demonstrate that ARGBL adoption in primary education has enhanced student learning performance.

Augmented reality can be applied not only to the sense of sight but also to other senses—hearing, smell, and touch [1]. AR-based applications can present learning content innovatively and easily for engaging special needs students. Quintero et al. [33] present a systematic review of AR in educational inclusion. This study reports the current state of AR for inclusive education by analyzing fifty articles from Scopus, Web of Science, and Springer published between 2008 and 2018. It was found that most of the studies were applied in the field of science. Students' increment in motivation, facilitating interaction, and attracting attention was also found as the most reported advantages. However, most of the studies did not mention the limitations of their work. Consequently, authors Quintero et al. [33] reported the possibilities to expand the research and learn the limitations of AR for inclusive education in the future. Other limitations reported by them include less sample size and a lack of technical discussion. They also enlightened the path of future work. It may be the expansion of the existing research studies by not only including aspects of disabilities but also other groups excluded from the educational process.

Theodoropoulos and Lepouras [47] conducted a review study on thirty-one studies in order to evaluate the characteristics and determine the benefits and drawbacks of AR in programming education. The authors stated that there is no doubt that augmented reality technology benefits programming learning. The result of the study demonstrates that in the majority of the studies, learners felt that AR technology improved their learning experiences by being intriguing and entertaining. Despite the benefits, using AR in programming learning has certain drawbacks, such as hardware demands, space restriction, difficulty in connecting with technology, and problems with managing feedback.

Wazirali [48] examined current augmented reality research to determine whether it was appropriate and compatible with Vision 2030's educational objectives. A total of sixty articles published between 2000 and 2020 were considered for review. This study goes into great length into the usage of augmented reality in education, its benefits, and its drawbacks to meet the educational objectives of Vision 2030. The findings of this study indicate that most studies were still in their infancy. The studies under consideration for research seem to have a relatively simple study design, used an exploratory methodology, performed test on condensed time frame, and considered a small number of participants. A future study focusing on developing meaningful instructional materials on AR for subjects besides science and mathematics was suggested by the author. Also, conducting educational research with a strong research design, larger sample size, and a thorough analysis to determine how AR affects learning was also considered crucial.

Siriborvornratanakul [4] reviewed modern AR from the start of the twenty-first century to the present. This study summarized the modern AR into five waves both within and outside of the research communities: (i) marker-based AR, (ii) projector-based AR (spatial AR), (iii) wearable AR, (iv) markerless AR, and (v) AR underneath artificial intelligence. Considering the current advancement in AI, it is expected that in the near future, AR systems would improve on the four previous waves in terms of intelligence, seamlessness, and engagement.

Lai and Cheong [8] examined the potential and limitations of AR in educational contexts by emphasising its uses in physics education. They mentioned two evaluation tools—(i) holistic evaluation model and (ii) SAMR model, which can be used to assess how successfully AR technology has been applied and, subsequently, how well it has been used in physics teaching. The results of the study show that marker-based AR and quantitative approaches are more frequently used in studies of augmented reality in education. They also noted that there is a lack of studies for use with more diverse groups and that most current studies are conducted for only a short amount of time. However, the authors admitted that they cannot say with certainty that AR has altered how physics is taught and studied because the technology has not yet developed to that stage.

In Table 1, we have summarized the key findings of the above-stated existing literature studies that discuss AR in education.

The aforementioned literature studies provide a summary of the works that describe the current state of the art of AR in the field of education. A closer examination revealed that almost all of the studies we surveyed covered different educational levels—from preschool to higher education. Combining various educational levels might illustrate the common challenges. However, it has often been observed that students in higher education are generally more acquainted with technology and mobile devices. However, this is not the case for primary-level students, particularly preschoolers, who have almost low or very limited experience in mobile-based applications. Based on this observation, we decided to concentrate on the effects of AR in PPS education. To the best of our knowledge, we found two literature reviews [36, 46] for PPS education. Among them, Fotaris et al. [46] examined the use of AR applications in primary education by considering seventeen studies. They mainly considered the articles that focused on AR game-based applications. Their findings highlighted the benefits and limitations of game-based learning in primary education. Masmuzidin and Aziz [36] exclusively discussed the recent advancements of AR technology in early childhood education. They examined twenty-four research articles published up through 2018 and documented the annual increase in publishing. This inspired us to look at the most recent articles for PPS education published up until 2021 to make sure their most current growth was not overlooked. However, when it comes to considering instructional AR applications, both game-based and nongame-based applications are a promising research topic for exploration.

This motivated us to conduct a systematic assessment of the literature on AR-based applications, taking into consideration a substantial number of studies that span all types of AR educational applications, notably for PPS education, to analyze the characteristics and weigh the pros and cons of integrating AR in PPS education. In general, this study will provide the current state of the art of AR in PPS education. The outcomes of this study will provide researchers with new insight into the field as well as information for AR application developers that will help them learn about the latest AR applications. Consequently, this review will motivate teachers to use cutting-edge teaching technology and aid students in effectively gaining academic knowledge.

## 3. Methodology

To carry out our proposed literature review, we followed the guidelines proposed by Kitchenham and Charters [49]. According to the guideline, the review process was divided into three stages:

(i) *Planning of review*: in this stage, we need to identify suitable research questions. Following this, we have to develop a review protocol by considering sources of data, search string, and study selection criteria (inclusion and exclusion).

(ii) *Conducting the review*: based on the study selection mentioned in the previous stage, we need to carry out the review in this stage—study selection, study quality assessment, and data synthesis.

(iii) *Reporting the review*: by considering our findings, the research questions need to be analyzed and discussed thoroughly in this section.

*3.1. Research Questions.* In this section, we aimed to develop suitable research questions for analyzing those articles published in the last ten years (2012-2021) in the area of AR-based applications for PPS education. The purpose of these

Table 1: List of existing review studies related to AR in education.

| References | Study overview | Research design | Study level (lower education/ higher education/both) | No. of studies reviewed | Benefits | Challenges |
|---|---|---|---|---|---|---|
| Sirakaya and Alsancak Sirakaya [35] | This study examined the trends of AR in education. | Quantitative | Both | 105 | According to their research, AR stands out as an effective educational tool that can be applied to various sample levels and training in a variety of fields. | Their research indicates that the main and most significant restriction is the technological issues that users have when utilizing AR. |
| Bacca Acosta et al. [34] | The review research reflects the state of AR in education from 2003 to 2013. | Quantitative | Both | 32 | The findings of this analysis suggest that learning gains and motivation are the two main benefits mentioned in the studies. | The most frequently mentioned drawback in this study's findings was that students had trouble maintaining the superimposed information. |
| Masmuzidin and Aziz [36] | In this study, the work that has been done so far in the field of early childhood education between 2009 and 2018 was presented. | Qualitative | Lower education | 24 | According to this study, motivation is one of the key benefits, and it is also said that children were more engaged, content, and attentive while using AR. | Not mentioned |
| Diegmann et al. [39] | This study presents the benefits of AR in education. | Qualitative | Both | 25 | We are given fourteen advantages by this study, and it also described how AR may be used in different directions for further advantages. | Ineffective classroom integration was one of the negative effects of AR that this review study discovered. |
| Chen et al. [38] | This review considered the AR studies in the educational environment published between 2011 and 2016. | Qualitative | Both | 55 | Their research discovered that motivation and learning improvements were the most frequently mentioned benefits of AR in educational settings. | Not mentioned |
| Akçayır M. and Akçayır G. [37] | The advantages and challenges of employing AR in education were discussed in this research. | Quantitative | Both | 68 | In this study, a number of advantages of AR were discovered, including learning achievement, motivation, and a positive outlook. | This study also identified certain usability issues, cognitive load issues, and technical limits with AR. |
| Sırakaya and Alsancak Sırakaya [41] | This study systematically investigated AR in STEM education. | Quantitative | Both | 42 | Four categories were used to categorize the advantages of integrating AR in STEM education: (a) contributions to the student, (b) educational outcomes, (c) interaction, and (d) other advantages. | Marker detection issues, lengthy content production times, and teachers' unwillingness to using AR applications were the main issues noted. |

Table 1: Continued.

| References | Study overview | Research design | Study level (lower education/ higher education/both) | No. of studies reviewed | Benefits | Challenges |
|---|---|---|---|---|---|---|
| Ibáñez and Delgado-Kloos [42] | This review presented AR in STEM education between 2010 and 2017. | Qualitative | Both | 28 | The result of this study reported that students were motivated, engaged, and had a positive attitude towards the STEM education with AR. | In this study, the noted challenges associated with AR technology are that it encourages student distraction and add to their cognitive load. |
| Pellas et al. [45] | The study provides the systematic review of ARGBL across primary and secondary education. | Quantitative | Both | 21 | The results of this study demonstrated that implementing ARGBL in primary and secondary education led to better learning outcomes. | The most prevalent restriction is that instructors are unable to use the same system for several academic subjects. |
| Fotaris et al. [46] | A systematic review of ARGBL applications in primary education from 2012 to 2017 was reported in this paper. | Quantitative | Lower education | 17 | The findings of this study demonstrate that ARGBL adoption in primary education has enhanced student learning performance. | The most common limitation is the absence of an integrated curriculum, which hinders teachers from utilizing the same system for diverse academic disciplines. |
| Quintero et al. [33] | This study presents a systematic review of AR in educational inclusion. | Quantitative | Both | 50 | The main advantages reported in this study are increasing motivation and felicitating interaction. | The issue identified in this study is the need to increase the sample size in research. |
| Theodoropoulos and Lepouras [47] | The application of AR in programming education is examined in this study. | Quantitative | Both | 50 | The study's conclusions demonstrate that AR has impact on perception, cognition, and motivation. | Spatial restrictions, hardware requirements, and specifications are the issues mentioned in this study. |

Table 2: Nine research questions developed by us.

| No. | Research questions |
|---|---|
| $RQ_1$ | What are the uses of AR applications? |
| $RQ_2$ | What are the pros and cons of AR applications? |
| $RQ_3$ | What are the different fields of education where AR applications are currently applied? |
| $RQ_4$ | What types of AR technologies are used at present? |
| $RQ_5$ | What types of devices are used and affordable? |
| $RQ_6$ | What are the software used for developing AR systems? |
| $RQ_7$ | What types of research methods are applied to examine the use of AR applications? |
| $RQ_8$ | What data collection methods are used in evaluating AR applications? |
| $RQ_9$ | Does AR as a pedagogy increase student's learning performance better than other traditional education? |

Table 3: Search string designed by us.

| No. | Search string |
|---|---|
| $S_1$ | ("Augmented Reality" OR "Mobile Augmented Reality") AND ("Preschool" OR "Primary Education"). |
| $S_2$ | ("Augmented Reality" OR "Mobile Augmented Reality") AND ("Preschool" OR "Primary Education") AND "Native Language". |
| $S_3$ | ("Augmented Reality" OR "Mobile Augmented Reality") AND ("Preschool" OR "Primary Education") AND "Game-based Applications". |

Table 4: Google Scholar findings.

| Search string | Number of articles returned | Total number of pages |
|---|---|---|
| $S_1$ | 8020 | 99 |
| $S_2$ | 291 | 28 |
| $S_3$ | 97 | 10 |

research questions is to seek answers about the working effects of AR in PPS education. Based on our understanding, altogether, we developed nine research questions ($RQ_1 \ldots RQ_9$) as presented in Table 2. It may be noted that the nine research questions were set only for encompassing the existing works of preschool and primary schools.

*3.2. Data Source.* To analyze our research questions, we need to consider a database of articles. There are different existing databases such as—ACM Digital Library, ScienceDirect, IEEE Xplore, Springer, Scopus, and ERIC. However, we found that Google Scholar considers almost all the databases mentioned above. Therefore, we decided to use it in our work. Our next step was to determine the search strings for searching in the Google Scholar database.

*3.3. Search String.* Based on the previous literature reviews and our understanding, we decided to use either augmented reality or mobile augmented reality as a mandatory part of our search string. As we were also focused on PPS education, preschool and primary education were also added as another mandatory choice in our search string. Accordingly, we constructed our first search string $S_1$ as shown in Table 3. It denotes ("Augmented Reality" OR "Mobile Augmented Reality") AND ("Preschool" OR "Primary Education"). We were further interested to review the works of PPS education using the native language. Accordingly, the second search string ("Augmented Reality" OR "Mobile Augmented Reality") AND ("Preschool" OR "Primary Education") AND "Native Language" represented as $S_2$ in Table 3 was designed. Last but not least, search string denoted as $S_3$ in Table 3 is used to search for that literature that reported game-based AR applications for PPS education.

*3.4. Inclusion and Exclusion Criteria.* Based on the three search strings $S_1$, $S_2$, and $S_3$ mentioned in Table 3, we searched the Google Scholar database. Our findings are listed in Table 4. Altogether, we found approximately eight thousand four hundred articles. As the number of articles was huge, we decided to add inclusion and exclusion criteria to focus on our requirements.

We developed five inclusion and exclusion criteria denoted by $IE_1$, $IE_2 \ldots IE_5$ as shown in Table 5.

The first criterion $IE_1$ considers the articles developed only for educational purposes and excludes the rest meant for other purposes. After obtaining the search results of the Google Scholar database, we found the presence of articles that are not associated with preschool and primary school education. Based on this observation, we further added the second criterion denoted as $IE_2$. According to this, we considered only preschool and primary education articles whereas the others were left out. We also found some documents in other languages except English. To exclude those, we proposed our third inclusion-exclusion criterion $IE_3$ as presented in Table 5. Although we were interested to review those articles associated with augmented reality, we observed that our search string returns many articles which consider virtual reality (VR) as well as mixed reality (MR). As we were interested to carry out this review only on AR

Table 5: Inclusion and exclusion criteria.

| No. | Inclusion | Exclusion |
|---|---|---|
| $IE_1$ | AR-based application developed for educational purposes | AR-based application developed for another purposes |
| $IE_2$ | AR application developed for preschool and primary students | AR application developed for others |
| $IE_3$ | Papers published in English language | Papers published in another languages |
| $IE_4$ | Research articles that use augmented reality technology | Research articles that use other (virtual reality and mixed reality) technology |
| $IE_5$ | Papers published between 2012 and 2021 | Papers published before 2012 and after 2021. |

Table 6: List of journals.

| No. | Journals: years | Total |
|---|---|---|
| 1. | Procedia Computer Science: 2013, 2018 | 4 |
| 2. | In Journal of Physics: Conference Series: 2019, 2020 | 4 |
| 3. | Journal of Educational Computing Research: 2017, 2019 | 2 |
| 4. | EURASIA Journal of Mathematics, Science and Technology Education: 2016 | 1 |
| 5. | International Journal of Education: 2018 | 1 |
| 6. | Early Childhood Education Journal: 2020 | 1 |
| 7. | Journal of Critical Reviews: 2020 | 1 |
| 8. | International Journal of Information and Education Technology: 2020 | 1 |
| 9. | International Journal of Information Technology: 2020 | 1 |
| 10. | International Journal of Interactive Mobile Technologies (iJIM): 2018 | 1 |
| 11. | International Journal of Educational and Pedagogical Sciences: 2015 | 1 |
| 12. | International Journal of Engineering Research Technology (IJERT): 2017 | 1 |
| 13. | Journal of Computer Science: 2020 | 1 |
| 14. | International Journal of Innovation and Learning: 2019 | 1 |
| 15. | Computers & Education: 2020 | 1 |
| 16. | Computers in Human Behavior: 2016 | 1 |
| 17. | Advances in Multimedia: 2018 | 1 |
| 18. | Journal of Multi Disciplinary Engineering Technologies: 2018 | 1 |
| | Total | 25 |

applications, the VR- and MR-based articles were excluded using the fourth criterion $IE_4$. Our final criteria denoted as $IE_5$ in Table 5 are to include the articles that are published only between 2012 and 2021 and exclude the articles published before 2012 and after 2021. This was done based on our objective to review the last ten years' articles.

*3.5. Study Selection.* The total record of articles identified from the Google Scholar database was 8408 articles. Using our five inclusion and exclusion criteria, we identified one hundred and ten articles. After examining the articles based on the title and abstract and cross-checking the redundant articles, we found eighty-two articles for our review. Although the title and abstract gave us an initial idea of suitability, after thoroughly reading those articles, we found that few of them are not associated with our objective. Altogether, eleven such articles were found and discarded for our review. In other words, we finally got seventy-one research articles suitable for our literature review. These seventy-one articles include one book chapter [50]. The rest seventy articles comprised of twenty-five journal articles and forty-five conference articles. In Tables 6 and 7, we reported those journals and conferences, respectively.

Although no specific quality assessment was done, we only chose the studies that addressed the creation of AR educational applications for PPS education. Analysis was done on the studies that comprised both user evaluation and non-user evaluation. After extracting the data from the 71 publications for evaluation, the results were summarized in a variety of metrics, including uses, advantages, disadvantages, AR type, the field of education, devices, software, research methods, and data-gathering tools. In the section that follows, the answers to the study's questions are presented together with an in-depth analysis and tabulation of each metric.

## 4. Result

In this section, we reported the answers to our nine research questions ($RQ_1$, $RQ_2 \ldots RQ_9$) as shown in Table 2. This was

Table 7: List of conferences.

| No. | Conferences: years | Total |
|---|---|---|
| 1. | International Conference on Interaction Design and Children (IDC): 2015, 2020 | 4 |
| 2. | International Symposium on Educational Technology. (ISET) IEEE: 2017 | 2 |
| 3. | Symposium on Computer-Human Interaction in Play (CHI PLAY): 2021 | 2 |
| 4. | International Symposium on Computers in Education (SIIE). IEEE: 2016, 2017 | 2 |
| 5. | International Workshop on Augmented Reality in Education (AREdu): 2020 | 2 |
| 6. | International Conference on Distance Education and Learning (ICDEL): 2018 | 1 |
| 7. | Central America and Panama Convention (CONCAPAN XXXIX). IEEE: 2019 | 1 |
| 8. | International Symposium on Mixed and Augmented Reality (ISMAR). IEEE: 2016 | 1 |
| 9. | Region 10 Conference (TENCON). IEEE: 2019 | 1 |
| 10. | International Conference on Human-Computer Interaction (HCCI): 2019 | 1 |
| 11. | IEEE International Conference on Multimedia and Expo (ICME): 2012 | 1 |
| 12. | International Conference on Computer and Informatics Engineering (IC2IE). IEEE: 2020 | 1 |
| 13. | International Conference on Augmented Reality, Virtual Reality and Computer Graphics: 2019 | 1 |
| 14. | International Conference on Software and Computer Applications (ICSCA): 2018 | 1 |
| 15. | Creativity and Cognition (C&C): 2021 | 1 |
| 16. | Conference on Information Systems and Technologies (CISTI). IEEE: 2012 | 1 |
| 17. | International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT). IEEE: 2019 | 1 |
| 18. | International Conference on Technology for Education (T4E). IEEE: 2019 | 1 |
| 19. | Interactive Mobile Communication, Technologies and Learning: 2017 | 1 |
| 20. | International Conference on Advancements in Computing (ICAC). IEEE: 2019 | 1 |
| 21. | International Conference on Industrial Automation, Information and Communications Technology (IAICT) IEEE: 2014 | 1 |
| 22. | International Conference on Digital Arts, Media and Technology (ICDAMT). IEEE: 2018 | 1 |
| 23. | International Conference on Computing Engineering and Design (ICCED). IEEE: 2019 | 1 |
| 24. | International Conference on Teaching, Assessment, and Learning for Engineering (TALE). IEEE: 2018 | 1 |
| 25. | International Conference on Emerging eLearning Technologies and Applications (ICETA). IEEE: 2019 | 1 |
| 26. | International Conference on Information and Communication Technologies in Education, Research, and Industrial Applications (ICTERI): 2019 | 1 |
| 27. | International Conference on MOOC, Innovation and Technology in Education (MITE). IEEE: 2014 | 1 |
| 28. | ACM Conference on Human Factors in Computing Systems (CHI): 2015 | 1 |
| 29. | Sciences and Humanities International Research Conference (SHIRCON). IEEE: 2019 | 1 |
| 30. | ACM International Joint Conference and 2018 International Symposium on Pervasive and Ubiquitous Computing and Wearable Computers (UbiComp): 2018 | 1 |
| 31. | International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct: 2018 | 1 |
| 32. | International Conference on Information Technology (ICIT). IEEE: 2017 | 1 |
| 33. | International Conference on Pervasive Computing and Communication Workshops (PerCom Workshops). IEEE: 2016 | 1 |
| 34. | Proceedings of SBGames: 2020 | 1 |
| 35. | International Conference on User Science and Engineering (i-USEr): 2018 | 1 |
| 36. | International Cognitive Cities Conference (IC3). IEEE: 2018 | 1 |
| 37. | In CSEDU: 2019 | 1 |
| 38. | International Conference on Informatics and Computing (ICIC). IEEE: 2016 | 1 |
| | Total | 45 |

done by analyzing the seventy-one articles selected for review. Our findings on those research questions are presented below.

*4.1. $RQ_1$: What Are the Uses of AR Applications?* We found AR applications usable and effective for learning as well as teaching tools for PPS education [51, 52]. This can also be used as an interactive and enjoyable tool for educating children [12, 53, 54]. Our review work has come across some interesting AR applications. This includes various AR-based activities for educating children as shown in Table 8.

The beneficial feature of AR applications is that they help children with self-learning [24]. In view of the findings

Table 8: AR-based applications.

| No. | Application purpose | Reference |
|---|---|---|
| 1. | AR application for learning daily prayers | Hidayat et al. [55]; Pradibta [56] |
| 2. | AR-based system to help children establish good character | Sarosa et al. [57] |
| 3. | An interactive AR game-based application for teaching music | Preka and Rangoussi [58] |
| 4. | Introducing animals to children with AR application | Marti et al. [59]; Wu et al. [5]; Zarzuela et al. [60] |
| 5. | AR system for children to learn alphabet by tracing letters | Nigam et al. [31] |
| 6. | Educational AR applications for understanding mathematical problems | Pritami and Muhimmah [61]; van der Stappen et al. [62]); Leitão et al. [50]; Purnama et al. [63]; Young and Santoso [64]; Young et al. [65]; Li et al. [66]; Kim et al. [67]; Radu et al. [68] |
| 7. | AR applications for educating natural science | Midak et al. [69]; Maijarern et al. [70] |
| 8. | AR system to enhance students' astronomical concepts | Antoniou et al. [53]; Fleck et al. [71]; Midak et al. [72] |
| 9. | AR platform for children to display online artworks | Chu et al. [73] |
| 10. | ARGBL approach to promote comprehensive reading in children | Tobar-Muñoz et al. [32] |
| 11. | Design of AR applications for teaching alphabets | Ablyaev et al. [74]; Nanda and Jha [16]; Rambli et al. [75]; Nigam et al. [31]; Hossain et al. [13] |
| 12. | To teach the usage of vowels to children | Cieza and Lujan [19] |
| 13. | Interactive AR applications for learning numbers | Tomi and Rambli [75]; Martínez et al. [76]; Cieza and Lujan [19] |
| 14. | Teaching vocabulary using AR technology | Che Hashim et al. [51]; Lee et al. [77, 78] |
| 15. | AR application for English language learning | Jain et al. [79]; Chen and Chan [80]; Fan and Antle [81]; Abd Majid et al. [82]; Pu and Zhong [83]; Dalim et al. [84]; Hossain et al. [13]; Vate-U-Lan [85]; Redondo et al. [86]; Topsakal and Topsakal [87]; Martínez et al. [88]; Lee et al. [78] |
| 16. | AR application for native language learning | Abrar et al. [17]; Hashim et al. [21]; Martínez et al. [76]; Meda et al. [22]; Montellanos et al. [23]; Motahar et al. [24]; Su et al. [25]; Zapata-Paulini et al. [26]; Hossain et al. [13] |
| 17. | To educate children about environmental studies | Wickramapala et al. [12] |
| 18. | To introduce fruits and vegetables with augmented reality | Syahidi et al. [14]; Yilmaz [15]; Hossain et al. [13] |
| 19. | To educate them about colours and shapes | Leitão et al. [50]; Yilmaz [15] |

as shown in Table 8, we may claim that AR applications can be a powerful technology for future education.

*4.2. RQ$_2$: What Are the Pros and Cons of AR Applications?* All the articles selected for the review may have their pros and cons. Starting with the identification of pros of AR-based applications for PPS education, we have identified seventeen advantages, denoted by $A_1$, $A_2 \ldots A_{17}$ in Table 9. It was observed that each of our reviewed articles can serve more than one advantage. However, we also found that all the articles do not have all these advantages. Therefore, we feel the necessity to map all the advantages concerning their reported studies as shown in Table 9.

Enjoyment, engagement and excitement ($A_1$), and learning gains ($A_2$) were found as the most inspiring aspect of AR. We found seventeen out of the seventy-one articles (24%) addressed these benefits. Accordingly, they are placed in the first two rows, denoted as $A_1$ and $A_2$ in Table 9. In the same line, easy-to-use and effective ($A_3$) and an increase in motivation ($A_4$) were observed among 21% and 20% of the reported articles, respectively. Following that, the two other advantages increase learning interest and felicitate interaction denoted as $A_5$ and $A_6$ were noticed. These advantages were reported in ten and nine articles. Increase participation and collaboration ($A_7$), improve memorization ($A_8$), increase attention ($A_9$), positive attitude ($A_{10}$), improve understanding ($A_{11}$), positive response ($A_{12}$), self-learning ($A_{13}$), low cost ($A_{14}$), improve communication skills ($A_{15}$), and increased attention span ($A_{16}$) were also listed as nine decisive factors for the acceptance of AR-based applications. The distribution of these advantages is reported in Table 9. We also noticed that there are two more advantages, reported in two different works [60, 83], respectively. In this paper, we grouped them and denoted as others ($A_{17}$) as shown in Table 9. This includes long-term knowledge and lower cognitive load. Children's increased motivation, learning gains, enjoyment, excitement, and other benefits may be signs that AR technology is having a positive educational impact in PPS education.

Except for the seventeen advantages, we also found eight disadvantages denoted by $D_1$, $D_2$,…$D_8$, represented in Table 10. We also came across with articles having more than one disadvantage. Therefore, these disadvantages were mapped concerning their related articles as shown in Table 10. It also figured out that twenty-one out of seventy-one articles have missed out to report their challenges. After excluding them, the rest fifty articles were analyzed by us. Among these, sixteen studies reported issues with user evaluation, denoted by $D_1$ in Table 10 as a major challenge. Followed by this, the two

Table 9: Identified advantages of AR applications in PPS education.

| No. | Advantages | No. of studies | Percentage |
|---|---|---|---|
| $A_1$. | Enjoyment, engagement, and excitement | 17 | 24% |
| $A_2$. | Learning gains | 17 | 24% |
| $A_3$. | Easy-to-use and effective | 15 | 21% |
| $A_4$. | Increase in motivation | 14 | 20% |
| $A_5$. | Increase learning interest | 10 | 14% |
| $A_6$. | Felicitate interaction | 9 | 13% |
| $A_7$. | Increase participation and collaboration | 6 | 8% |
| $A_8$. | Improves memorization | 4 | 6% |
| $A_9$. | Increase attention | 4 | 6% |
| $A_{10}$. | Positive attitude | 3 | 4% |
| $A_{11}$. | Improve understanding | 3 | 4% |
| $A_{12}$. | Positive response | 3 | 4% |
| $A_{13}$. | Self-learning | 3 | 4% |
| $A_{14}$. | Low cost | 2 | 3% |
| $A_{15}$. | Improves communication skills | 2 | 3% |
| $A_{16}$. | Increase attention span | 2 | 3% |
| $A_{17}$. | Others | 2 | 2% |

Table 10: Identified disadvantages of AR applications in PPS education.

| No. | Disadvantages | No. of studies | Percentage |
|---|---|---|---|
| $D_1$. | Issues with user evaluation | 16 | 32% |
| $D_2$. | Technical problem | 13 | 26% |
| $D_3$. | Usability issues | 11 | 22% |
| $D_4$. | Low sample size for user study | 6 | 12% |
| $D_5$. | Needs for proper lightning condition | 4 | 8% |
| $D_6$. | Requires gadgets that have camera, gyroscope, accelerometer sensors, GPS, and internet connection | 3 | 6% |
| $D_7$. | Limited budget for single-used instructional tool | 3 | 6% |
| $D_8$. | Others | 8 | 16% |

disadvantages—technical problems ($D_2$) and usability issues ($D_3$)—were observed in 26% and 22% of the reported studies, respectively. We noted that the technical issues arise due to the difficulties in recognition of image targets, occlusion, the requirement of pretraining to use the AR applications, and consuming high power and memory. Usability issues encompass the requirement for a better user interface (UI) and difficulties in handling the markers to produce the required 3D target images. It was also observed that the teachers are considered as the end users of AR applications. Often, they can not customize these AR applications according to their needs. The other disadvantages observed are low sample size for user study ($D_4$); need for proper lightning condition ($D_5$); requiring gadgets that have a camera, gyroscope, accelerometer sensors, GPS, and internet connection ($D_6$); and limited budget for single-used instructional tool ($D_7$). The pitfall $D_4$ was found in six articles, while 4 studies reported $D_5$. The other two disadvantages $D_6$ and $D_7$ were found among 6% of the reported fifty articles. There are some other flaws which include a low level of cognitive attainment [15], lack of strong collaboration and personalization of elements [53], banned on mobile phones in primary school [12], requirement of more subjects [23], less information about AR applications [78], problems in understanding symbolic meanings of icons [81], and children's health concerned by parents [77, 78]. In Table 10, they are grouped and reported as others ($D_{10}$).

*4.3. $RQ_3$: What Are the Different Fields of Education where AR Applications Are Currently Applied?* Considering the field of education where AR applications can be applied for PPS education, we have identified sixteen educational fields (denoted by $F_1$, $F_2 \ldots F_{16}$), as shown in Table 11. According to our findings, 39% of the studies developed AR applications for English language study, as denoted by $F_1$.

Mathematics problem solving ($F_2$) and native language learning ($F_3$) were also identified as the other two educational fields. These two fields are reported in ten and eight out of the seventy-one articles. Combination of English and native language teaching (6%), animal recognition (6%), science education (4%), astronomical studies (4%),

Table 11: AR in various fields of education for PPS education.

| No. | Category | No. of studies | Percentage |
|---|---|---|---|
| $F_1$. | English language study | 28 | 39% |
| $F_2$. | Mathematics problem solving | 10 | 14% |
| $F_3$. | Native language learning | 8 | 11% |
| $F_4$. | Combination of English and native language teaching | 4 | 6% |
| $F_5$. | Animal recognition | 4 | 6% |
| $F_6$. | Science education | 3 | 4% |
| $F_7$. | Astronomical studies | 3 | 4% |
| $F_8$. | Daily prayer practicing | 2 | 3% |
| $F_9$. | Environmental studies | 2 | 3% |
| $F_{10}$. | Character education | 1 | 1% |
| $F_{11}$. | Book learning | 1 | 1% |
| $F_{12}$. | Music teaching | 1 | 1% |
| $F_{13}$. | Comprehensive reading | 1 | 1% |
| $F_{14}$. | Fostering collaboration | 1 | 1% |
| $F_{15}$. | Emotion learning | 1 | 1% |
| $F_{16}$. | Creating art show | 1 | 1% |

Table 12: Types of augmented reality used in PPS education.

| No. | Types | No. of studies | Percentage |
|---|---|---|---|
| $M_1$. | Marker-based | 62 | 87% |
| $M_2$. | Markerless | 3 | 4% |
| $M_3$. | Location-based | 1 | 1% |
| $M_4$. | Both marker-based and markerless | 2 | 3% |
| $M_4$. | Not specified | 3 | 4% |

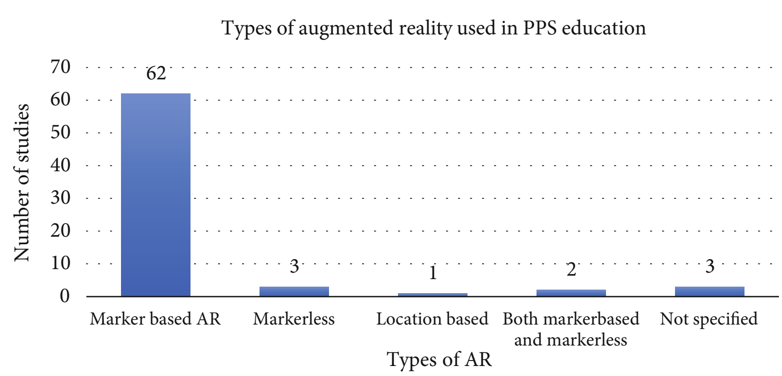


Figure 1: Types of AR used in PPS education.

daily prayer practicing (3%), and environmental studies (3%) were also identified as six areas, denoted as $F_4$, $F_5$ …$F_9$ in Table 11 where AR has been adopted. Besides this, there are other areas where we found the use of AR. This includes character education ($F_{10}$), book learning ($F_{11}$), music teaching ($F_{12}$), comprehensive reading ($F_{13}$), fostering collaboration ($F_{13}$), emotion learning ($F_{15}$), and creating art shows ($F_{16}$). Table 11 includes the number of articles observed for these areas. It may be noted that each of these areas was reported only in 1% of total articles.

*4.4. $RQ_4$: What Types of AR Technologies Are Used at Present?* Marker-based AR ($M_1$), markerless AR ($M_2$), and location-based AR are shown in Table 12 were identified as three different types of AR technologies used for AR application development. Marker-based AR uses a marker where the virtual objects are positioned to be placed. It is the most used AR type because it provides static markers such as flashcards, cards, books, magazines, and QR codes that provide a stable tracking process. On the contrary, markerless or location-based AR does not require any marker. It relies on

Table 13: Types of devices used in PPS education.

| No. | Types | No. of studies | Percentage |
|---|---|---|---|
| $H_1$. | Handheld devices (smartphone & tablets) | 63 | 89% |
| $H_2$. | Personal computer (desktop or laptops) | 8 | 11% |

Table 14: Types of research methods observed in PPS education.

| No. | Research methods | No. of studies | Percentage |
|---|---|---|---|
| $RM_1$. | Quantitative method | 26 | 37% |
| $RM_2$. | Mixed method | 14 | 20% |
| $RM_3$. | Qualitative method | 10 | 14% |
| $RM_4$. | Not specified | 21 | 30% |

mobile device hardware such as a camera, accelerometer, Global Positioning System (GPS), and digital compasses for identifying a device's position and location. It is mostly used for outdoor educational purposes—field visits—and game-based application purposes. In our survey, we found 87% of our reviewed articles used the marker-based AR approach, denoted as $M_1$ in Table 12, while markerless AR ($M_2$) and location-based AR ($M_3$) were reported in three and one articles, respectively, as shown in Figure 1. We also came across two articles that use both marker-based and markerless ($M_4$), resulting in 3%. Further, we have also identified that three out of seventy-one articles (4%) have missed out to report the AR types used denoted as $M_4$ in Table 12.

*4.5. $RQ_5$: What Types of Devices Are Used and Affordable?* In this review, handheld devices have been identified as the most used technology for AR educational application development. Out of the total of seventy-one articles selected for review, sixty-three were designed for handheld devices ($H_1$ ), resulting 89%. The most widely used devices for MAR applications were smartphones and tablets. We noticed that the handheld devices are mainly used due to their familiarity and portability for all groups of users [89], including kids. The rest 11% works considered personal computer (denoted as $H_2$), as shown in Table 13.

We also noticed the acceptance of AR-based applications due to the affordability of low-cost mobile devices. AR works on mobile devices without the requirement of any costly additional devices. This makes AR applications a potential medium to be used in schools.

*4.6. $RQ_6$: What Are the Software Used for Developing AR Systems?* In this study, we have observed that 55% of the reported studies have used the Unity game engine for the development of AR applications. Following that, the Microsoft XNA game studio framework was also used in one study [90]. Further, three articles reported the use of *Aurasma Web-Based Studio* for AR application development.

In the context of AR Software Development Kits, Vuforia SDK was majorly reported to be used in thirty-three out of seventy-one articles. Android SDK and ARToolKit SDK were adopted in six and three articles, respectively. Kudan and ARCore SDKs were also reported, and each of these software was used in two articles. Goblin XNA and ALVAR 2.0 were also applied in one article.

To develop 3D assets, we noticed that Blender, Photoshop CS6, SketchUp, Maya, Cinema4D, and Substance Painter were used. Blender was reported in seven articles, while each of the other five software was reported in one study.

The other software reported are Emgu CV2.4 and programming languages such as C#, C, Java, and Ruby programming for the development of AR applications.

*4.7. $RQ_7$: What Types of Research Methods Are Applied to Examine the Use of AR Applications?* In this review, we found that quantitative research method ($RM_1$) is mainly used to judge the suitability of the different AR applications for preschool and primary studies. Out of the total seventy-one articles, twenty-six have used this approach, resulting in 37% of total studies, as shown in Table 14. Following this, the mixed method ($RM_2$) which comprised both quantitative and qualitative approaches was observed in fourteen articles. While fourteen percent of the work used the qualitative method ($RM_3$), the rest twenty-two articles missed out to adopt any of the above three approaches.

*4.8. $RQ_8$: What Data Collection Methods Are Used in Evaluating AR Applications?* After carefully going through our seventy-one articles, we noticed that twenty-five studies have missed evaluating their research data. Excluding these studies, we analyze the data collection methods of the rest of the forty-six articles as shown in Figure 2. Altogether, we found five data collection techniques—questionnaire, observation, interview, survey, and feedback used for analyzing their works, as denoted by $DC_1$, $DC_5 \ldots DC_5$ in Table 15. In this context, it may be noted that seventeen studies have considered more than one data collection method. Therefore, we mapped all the data collection methods with respect to their reported articles in Table 15. Twenty-six out of forty-six articles, resulting in 57%, used questionnaire-based evaluation ($DC_1$) as shown in Figure 2. We also found that 39% of the study used an observation-based method ($DC_2$). Followed by this, interview ($DC_3$) and survey ($DC_4$) methods were also observed to be used in fourteen and nine articles, respectively. 15% of the reported articles were observed following the feedback ($DC_5$) evaluation method.

*4.9. $RQ_9$: Does AR as a Pedagogy Increase Student's Learning Performance Better than Other Traditional Education?* Traditional education methods can be a monotonous medium of learning, especially for children [91]. After analyzing all the studies carefully, we found that AR applications can be used as an alternative medium of fun learning for students. An increase in learning performance with AR applications

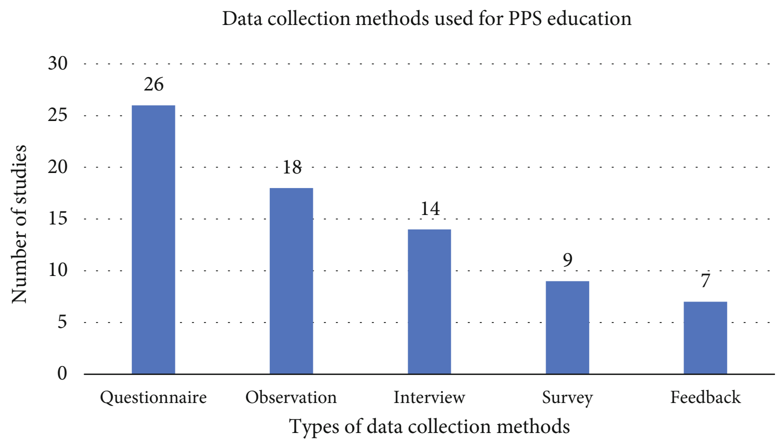


Figure 2: Types of data collection methods for PPS education.

Table 15: Types of data collection methods used for PPS education.

| No. | Data collection method | No. of studies | Percentage |
|---|---|---|---|
| $DC_1$. | Questionnaire | 26 | 57% |
| $DC_2$. | Observation | 18 | 39% |
| $DC_3$. | Interview | 14 | 30% |
| $DC_4$. | Survey | 9 | 20% |
| $DC_5$. | Feedback | 7 | 15% |

compared to other traditional methods was also reported [29, 55, 86, 91, 92]. By applying AR applications in the classroom, educators can train and maintain the level of learning interest among students [21, 59, 70, 91, 92]. We observed that AR application can provide better visualization of abstract concepts [67, 69], understand complex subjects easily [50], learn the exact pronunciation [23, 87], can memorize more words [16, 55, 91], and perceived deeper knowledge with AR application. It can also increase students' motivation for learning [23, 65, 66, 86, 88, 93]. As a consequence, AR as a pedagogy may be more effective than the traditional teaching-learning process.

## 5. Discussion

This literature study reviewed AR-based applications developed for preschool and primary school education between 2012 and 2021. We have selected seventy-one articles from Google Scholar database, which includes one book chapter, twenty-five journals, and forty-five conference papers. Our study analyzed the current state of AR educational applications and summarized the results in terms of uses, advantages, disadvantages, challenges, types of AR, devices, affordances, research methods, data collection tools, software, and fields of education.

The literature review was conducted using the inclusion and exclusion criteria provided in Table 5. We have restricted our work only to examining augmented reality and not considered mixed reality (MR) or virtual reality (VR). Both MR and VR-based applications provide immersive experiences, but they typically need the usage of additional wearable equipment. These devices are generally costly. As a result, they may be expensive for those schools with limited or low budgets. These devices can also be uncomfortable to wear. In addition, they may be risky for the students, particularly for kids. On the other hand, AR applications require mobile devices, tablets, or laptops, which have already become a part of our life due to their affordability.

Our work was conducted to examine the detailed characteristics of AR educational applications. To analyze the related works, we proposed nine research questions denoted as $RQ_1$, $RQ_2 \ldots RQ_9$ in Table 2. It may be noted that these questions are independent in nature. In this work, we have observed that the number of articles published on AR applications has increased progressively in the last four years. Among them, marker-based AR applications were mainly developed for PPS education. The static target image is considered to be most comfortable for the kids. In previous review studies [34–36, 46], marker-based AR has been reported as the most preferred technique for educational applications. The other approach—markerless—eliminates the need for markers. Consequently, it can be used anywhere in the real-time environment. Therefore, this approach may become popular in the forthcoming years. During the review process, we found several works on higher studies using AR. It was also observed that these studies mostly neglect the effects of AR on PPS education. On the contrary, our review was carried out keeping PPS education as the main interest of focus. Another important issue observed in our review is the missing of user-based evaluation by most of the researchers. Nevertheless, prototype testing and expert judgment were used. However, without user-based evaluation, they may miss out the essence of user-centric development. Additionally, it was observed that none of the publications we analyzed employed devices such as head mounted displays (HMD) or AR headsets (Google Glasses and HoloLens). The users' discomfort with the equipment may be the cause of this. The expensive price of these devices may be another factor. Nevertheless, hopefully, the latest technological advancement might make AR headsets widely available at a reasonable price.

In the context of research methods, we found three different approaches—quantitative, qualitative, and mixed methods. After doing a critical analysis, we found that mixed method may be a suitable candidate for future research. This is because it can reveal the quantitative data as well as the qualitative properties of AR-based applications.

Out of the seventy-one reviewed articles, 39% of the works have adopted observation-based methods for data collection. A questionnaire-based approach was observed among 57% of the reviewed article. It signifies the popularity of this method among researchers. A questionnaire-based approach may be suitable for collecting data from adult participants. However, we feel that this may not be a suitable method for preschool and primary students. The main reason may be the mental ability of the kids to interact with the AR researchers as well as some unknown platforms of AR. This unfamiliarity may cause a delay in evaluating AR applications. As a result, overall development time can increase significantly. We also noticed that many researchers had conducted interviews and surveys with teachers and parents, whereas questionnaires were answered by parents on behalf of students [17, 55, 94] in most of the cases. Considering the mental ability of preschoolers and primary students, we can suggest the suitability of the observation-based approach over others.

This study has identified several advantages that provides students with enjoyment, engagement, excitement, and motivation. It also enhances students' learning gains and provides user-friendly applications. Benefits from prior research also include learning gains, motivation, engagement, enjoyment, and collaboration [34, 36, 39, 46, 47]. Although AR applications provide several benefits, we also came across some challenges and issues of AR applications. Since AR is a new technology, students require assistance to operate AR applications [51]. Pretraining is also required for those students using it for the first time. Not only children but teachers and parents may also face the same challenge. The requirement of proper explanation about the applications is also essential to avoid misunderstanding of symbolic icons' meaning [81]. Therefore, usability issues of AR-based applications may be considered as a predominant challenge for PPS students. Except for usability, acceptance of AR applications was also another important challenge, observed by us. In most countries, we found that electronic gadgets—mobiles, tablets, and laptops—are not being used, particularly for preschool and primary medium. This can create difficulties in adopting AR applications as a means of teaching and learning both for students as well as teachers [12]. We further noticed that the requirement of devices and internet connections, for operating AR applications, was also an issue in rural schools as reported by Pritami and Muhimmah [61], Maijarern et al. [70], and Fan and Antle [81]. Cognitive overload is also noted as another challenge. Children often need to follow the software instructions to run AR applications. At the same, they need to learn a particular topic presented by the AR applications. Teaching children with rich content—animations, 3D objects, and constant guidance—can also exhaust young students' cognitive abilities. Consequently, it can affect their learning [6, 95]. Occlusion—the blockage of the target image by any physical objects—may affect the performance of AR applications. This may result in difficulties in tracking. Blockage of the marker in the marker-based approach may not reproduce the augmented contents properly. As a result, students may get confused [81]. The prolonged use of AR applications can also affect children's health. Side effects like addiction to electronic devices and lack of interaction with a human may be serious issues for parents and teachers. It might also have an adverse impact on students' motor skills and social development [94]. Other health issues that need to be concerned about are eye infections, back pain, and obesity.

Based on our observation, we can say that AR applications might be useful for preschool and primary education provided that some improvements are done. We also suggest further improvements and future directions for AR applications. This includes the following:

(i) Designing a more attractive and interactive user interface (UI) of AR applications to draw students' attention

(ii) Improvement in the detection of a target image, rendering of images, and adding voice control for navigation

(iii) Providing more learning content and information

(iv) Suitability of simple AR applications saves memory and battery life for mobile applications

(v) Usability validation using a large sample size and long-time span

(vi) Investigating the use of markerless AR applications in future

(vii) To further explore the AR applications developed for secondary and higher education

## 6. Conclusion

A systematic review focusing on augmented reality applications for preschool and primary education for the last decade was carried out in this work. Altogether, seventy-one articles from the Google Scholar database were selected. Using our proposed nine research questions, we tried to investigate the uses, advantages, disadvantages, challenges, types of AR, devices, affordances, research methods, data collection tools, software, and fields of education. After carefully analyzing the research questions, we found that there are challenges—usability issues, acceptance of technology, technical problems, cognitive overload, and health issues. Despite that, there are many areas where AR-based applications may serve as another means of teaching with the traditional teaching-learning methods. This includes English language study, mathematics problem solving, native language learning, astronomical studies, science education, environmental studies, and many more. This review may help those researchers who are keen to explore the domain of AR applications in educational settings. In the future, AR technology has the potential to hype education levels.

## Data Availability

Data is available with author.

## Conflicts of Interest

The authors declare that they have no conflict of interest.

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