A Systematic Review of Augmented Reality Design for Young Children

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Abstract—Augmented Reality (AR) has become one of the important tools in teaching and learning, which is made evident by an increasing number of studies focusing on such technology over the past few years. However, studies focusing on the design of AR applications for young children have been seriously lacking and no framework for designing AR for young children has been proposed before. The importance to have a framework for young children is crucial, as their cognitive, skills and preferences are different from the older user groups, and to ensure the apps meet the pedagogical standards and age appropriate. This paper provides the findings in which the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) method was used to select and critically review articles from Scopus and Web of Science databases. Overall, 16 articles were selected, which revealed five themes: (1) information, (2) interface, (3) interaction, (4) imagination, and (5) immersion. All five themes related to the design aspects need to be carefully addressed and considered in developing AR applications for young children. The findings of this study can be used as a guideline for AR developers to ensure their products can be both efficacious and entertaining, improve children's learning performance, motivation, and interest.

Keywords—augmented reality, design of learning applications, motivation, systematic literature review, young children

1 Introduction

Augmented Reality (AR) is a technology that allows users to view texts, images, audio, videos, and animations by scanning an object in the real world. As highlighted in the literature, this technology has been given many definitions [1]. However, according to [2], such technology has three main characteristics as follows: (i) consists of a combination of real-world objects and virtual elements, (ii) highly interactive, and (iii) based on three-dimensional (3D) rendered environment.

Over recent years, AR technology has been widely used in many areas, such as business (advertising and marketing), medical (surgery and pharmaceutical), military, science, technology, entertainment (games and films), and education. In the educational realm, this technology has been implemented in various levels of education ranging from early childhood education to tertiary education. Its use has become more pervasive and intense in education as there is mounting evidence from studies that show such technology can improve teaching and learning. Specifically, the use of AR applications or tools can improve students' performances and motivation [3-6], facilitate learning [7], increase students' interest in lessons [8], enhance participation in learning [9], develop positive attitudes, enhance spatial skills, facilitate cooperative learning [10], make learning fun, and decrease cognitive load [11-12].

Despite the high number of studies that have been devoted to studying the implementation of AR technology in the educational field, two main issues have emerged that highlight some inadequacies of such studies. Based on a systematic review conducted by [12-16] the first issue relates to the scope of research in that existing studies are mainly concerned with primary, secondary, and tertiary levels of education. By contrast, as revealed in a study by [12-15] only a few studies have been carried out thus far that deal with early childhood education of preschool and kindergarten students. This statement has been supported by the recent study by [17], where younger age groups have often received less attention in any research, and this is due to the fast development of young children's cognitive abilities [18-19].

As revealed in a study by [20], the second issue is that the focus of most AR studies in education tends to concentrate on the implementation aspects and not so much on the design aspects of AR applications. In particular, the design aspects of AR learning applications for young children, such as preschoolers, have not been widely researched [21]. Surely, strong knowledge in design is important [22] to ensure smooth, effective implementation and use of technological learning applications where the lack of which can be detrimental to student learning.

Often, developers create applications for children by purely relying on their childhood experiences, which may not necessarily be sufficient and relevant to make the learning applications effective. Due to the passing of time, what they think to be important may not hold to be true anymore as today's children have different preferences and needs. For instance, in terms of content design, the past generations of young children can be entertained with the same repetitive sequence of events without being bored [23]. But now, according to a recent finding, the continuous use of the same multimedia elements in a learning application can lead to boredom among children because they could predict events that would take place in their learning [24]. Meanwhile, another example can be seen in terms of interaction. The young children interaction with devices such as tablet and mobile phone are totally different with computer, and the way they interact must be carefully taken into consideration, as nowadays these two platforms no longer require extensive computer skills such as the use of keyboard and mouse [25]. Such finding strongly suggests that designing learning applications based on a wide range of technologies, including AR technology, for young children entails a firm understanding of design principles, without which such applications will be rendered inefficacious.

Premised in such a context, the researchers undertook this study to conduct a systematic review of the current literature to help understand the current design guidelines for learning applications based on AR technology for young children. As stated by [26], a strong understanding of the effects of AR can assist researchers and developers to make suitable design choices by focusing on the advantages of their affordances to enhance young children's learning experience. Certainly, a set of guidelines for designing AR technology-based applications for young children needs to be established to ensure such applications can perform optimally, meets the age-appropriate and pedagogical standards, as nowadays, there are many applications in the market but designed with the lack of quality as aforementioned [27]. As such, this review carried out with the main objective of examining the appropriate design guidelines for the development of AR applications for young children. The findings can be used by the AR developer in any domain and subjects as long as the AR app is designed and developed for early childhood education.

The paper is structured as follows: Section 1 explains the purpose of conducting the systematic review while Section 2 details the methodology used, namely the PRISMA Statement (preferred reporting items for systematic review and meta-analysis) approach. Then, Section 3 discusses the review and synthesis of design guidelines for AR learning applications for young children, while Section 4 explains about the guideline. Finally, Section 5 provides the direction of future research and ends with a summarization of research in Section 6.

2 Methodology

This section explains the method used to review the current literature regarding Augmented Reality design for young children. In this study, the researchers used an adapted method called PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) that included resources (such as Scopus and Web of Science) to run the systematic review based on keywords (see Table 1), the inclusion (eligibility) and exclusion criteria, steps of the reviewing process (identification, screening, eligibility), data abstraction, and analysis.

2.1 The PRISMA statement

The PRISMA Statement was developed to offer a systematic way for researchers to conduct and report systematic reviews and meta-analyses [28-31]. PRISMA has three unique advantages as follows: (1) it can define clear research questions that facilitate systematic research, (2) it can identify inclusion and exclusion criteria, and 3) it can examine a large database of scientific literature in a pre-defined time. Therefore, this methodology was deemed highly appropriate to guide the researchers in identifying relevant information regarding AR design that could help enhance young children's motivation in learning.

2.2 Resources

This systematic review used two well-known databases, namely Web of Science and Scopus [32], which are highly reputable sources consisting of tens of thousands of scientific and technical papers, books, reports, and others. For example, the Web of Science has a collection of more than 21,777 journals, books, and conference proceedings gathered since 1900, with each journal being rigorously reviewed prior to publication. Scopus was created by Elsevier in 2004 and according to [32], Scopus has more than 20,500 peer-reviewed journals published in 5,000 publishers, more than 1200 Open Access journals, over 600 trade publications, 500 conference proceedings, and 360 book series from all areas of science.

2.3 Inclusion (eligibility) and exclusion criteria

This study determined several inclusion (eligibility) and exclusion criteria to help select relevant articles for analysis (see Table 2). The first criterion was the document type that determined only journal articles and conference papers were to be selected, which means that reviewed articles, book series, books, and book chapters were all excluded. The second criterion was the timeline, which was within 2011-2020 (a span of 10 years), that essentially helped the researchers to focus on relevant and recent articles on Augmented Reality research, which also helped highlight the evolution of such a novel technology. In addition, [33] stated that it is very impossible for researchers to evaluate all published articles; as a result, researchers should determine the time period within which they will analyse and submit their review findings properly.

Given that young children were the target group; the third criterion was the subjects' age that focused on the pre-operational group of children (aged 2 – 7). On the other hand, articles pertaining to such a group of children with disabilities, special needs, autism, and Down Syndrome were excluded. The fourth criterion was language such that only articles written in English were selected and those written in other languages were excluded in the selection process. Such exclusion was important to avoid the need for the translation of such articles into English. The fifth criterion was the area of study in those only articles relating to education were selected.

2.4 The systematic review process

This systematic review process was conducted in January 2020 by adapting PRISMA Statement developed by [31] which involving four stages. The first stage was to identify the keywords for the search of relevant articles, such as the words 'augmented reality' and 'preschoolers'. Identifying the correct terms to be used in the research is important as it will affect the amount of paper to be retrieved from the database [28]. In terms of word selection for Augmented Reality, the research decided not to use the Augmented Reality acronym like 'AR', as it will produce massively false positive outcomes. This research also did not used the term Mixed Reality as it is the combination of Augmented Reality and Virtual Reality technology, and this is beyond of the research objectives and scopes. Meanwhile, in terms of word selection for 'preschoolers', this research used variety of synonyms (based on thesaurus ad existing research commonly used term) and found out a few similar words that related to preschoolers such as 'early childhood', 'child', 'young children', 'youngster', and 'kid'. Meanwhile, any keywords related to disabilities were excluded because children with disabilities and impairment have different needs compared to normal children [34]. Based on such keywords, 1519 articles were retrieved consisting of 382 articles from Web of Science (WoS), 689 articles from Scopus, and 448 articles from other additional resources, including Science Direct (n=63), IEEE Xplore (n=363), and Google Scholar (n=22).

The second phase involved the screening of the 1519 retrieved articles that removed 1354 articles based on inclusion and exclusion criteria. The third phase involved a careful review of the remaining articles. After careful examination, only 16 articles were selected for further analysis. A majority of articles were not selected as they did not have such keywords in their main texts, including articles that only mentioned the term 'augmented reality' in their reference section. Table 1 and Table 2 show the keywords and inclusion and exclusion criteria used in the systematic review process, respectively.

Table 1. Keywords used in the systematic review process

Databases	Keywords used
Scopus	TITLE-ABS-KEY (("AUGMENTED REALITY") AND ("PRESCHOOL*" OR "PRE-SCHOOL" OR "EARLY CHILDHOOD" OR "EARLY EDUCATION" OR "CHILD*" OR "YOUNG CHILDREN" OR "KID" OR "YOUNGSTER") AND NOT ("AUTIS*" OR "DISABL*" OR "SPECIAL NEED*" OR "REHAB*" OR "CEREBRAL PALSY"OR "IMPAIRMENT*"OR "ASD" OR "ADHD" OR "DOWN SYNDROME" OR "MOTOR IMPAIRMENT"))
Web of Science	TS= (("AUGMENTED REALITY") AND ("PRESCHOOL*" OR "PRE-SCHOOL" OR "EARLY CHILDHOOD" OR "EARLY EDUCATION" OR "CHILD*" OR "YOUNG CHILDREN" OR "KID" OR "YOUNGSTER") NOT ("AUTIS*" OR "DISABL*" OR "SPECIAL NEED*" OR "REHAB*" OR "CEREBRAL PALSY"OR "IMPAIRMENT*"OR "ASD" OR "ADHD" OR "DOWN SYNDROME" OR "MOTOR IMPAIRMENT"))

Table 2. The inclusion and exclusion criteria used in the systematic review process

Criterion	Eligibility	Exclusion
Document type	Journal and conference	Journal (Systematic Review), book series, book, chapter in book
Language	English	Non-English
Timeline	2011-2020	< 2011
Target User	Pre-operational user group	Less than 2 years, more than 7 years Disabilities
Domain	Education	Non-education
Accessibility	Open access	Not open access

2.5 Data abstraction and analysis

The remaining 16 articles selected from the systematic review process were analyzed to help address the research objective (see Section 1). First, the analysis involved the reading of the abstract of each article to highlight relevant main themes and sub-themes. Then, an in-depth reading of each article was performed to collect more detailed information related to the research objective. Figure 1 shows the flow of data abstraction and analysis conducted in this study based on the adaptation of PRISMA Statement.

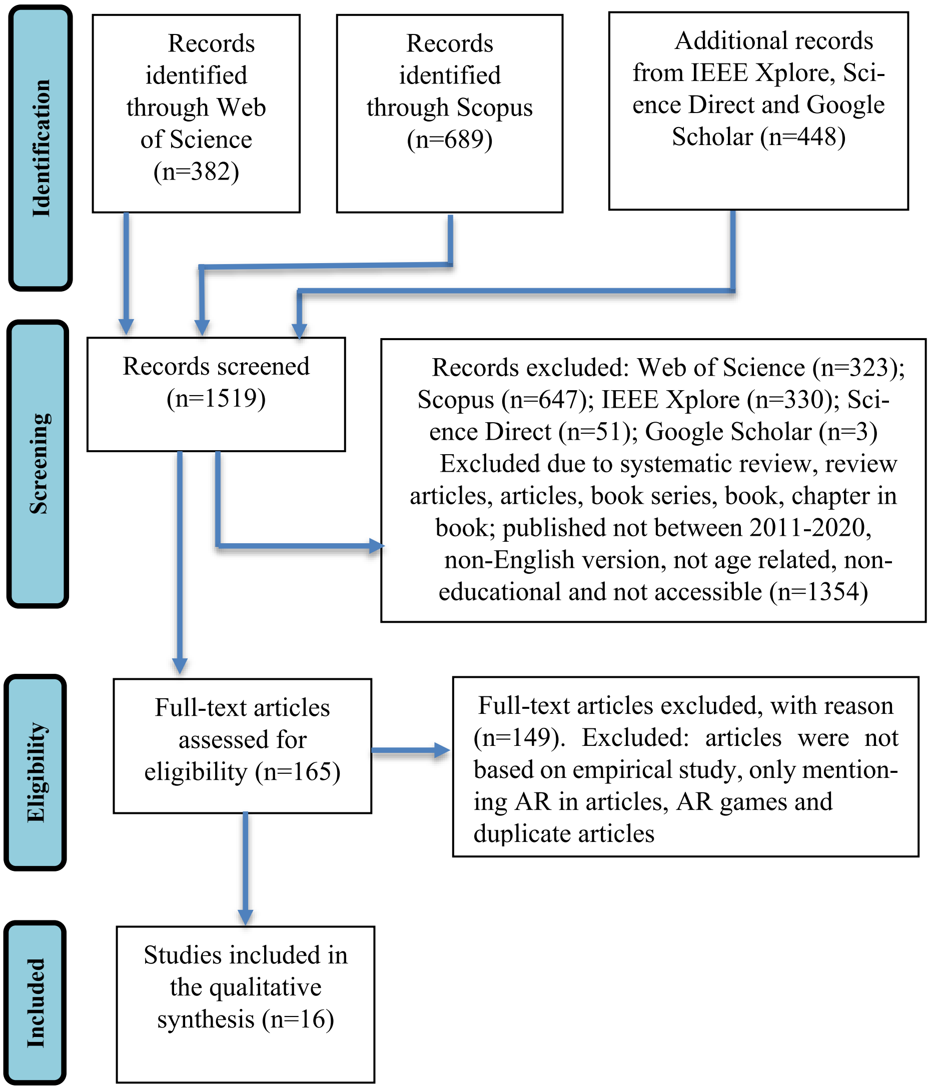

Fig. 1. The flow of data abstraction and analysis adapted from [31]

3 Results

From the systematic review, five main themes and nine sub-themes related to the research objective were identified. The five main themes are as follows: (1) information design (with three sub-themes), (2) interface design (with one sub-theme), (3) interaction design (with two sub-themes), (4) imagination (with two sub-themes), and (5) immersion (with one sub-theme). The following subsections discuss the results of a comprehensive analysis of the current design of augmented reality applications for young children.

3.1 Information design

Information is one of the important elements in the design of AR applications for young children. Without interesting and compelling information, such applications will only become technology novelty. In this review, information design could be categorized into three subthemes as follows: (1) physical content design, (2) virtual content design, and (3) marker design.

Physical content design. Content design is one of the vital features that have a huge impact on the use of any technology. According to [36], AR learning applications need to be designed with curriculum and pedagogy in mind to engender meaningful learning experiences in the classroom. More importantly, application developers and instructional designers must ensure that the learning contents of such applications are appropriate with preschoolers' age as their cognitive and emotional developments, needs, skills, and knowledge are different from those of older students. As such, when designing physical contents for AR learning applications for children (e.g., AR Books), developers must take into account children's abilities, language capabilities (reading), and understanding of such contents, as children at such a tender age generally do not have good reading skills. Failure to consider such factors can make such applications difficult to handle, which can eventually make such children unmotivated or frustrated to learn.

As reviewed, most of the studies of AR learning applications for preschoolers involved learning content based on the preschool curriculum. For example, studies carried out by [37-39] involved AR applications containing contents based on the preschool book activity. Likewise, other studies conducted by [24, 40-48] involved AR applications containing contents based on specific topics of the preschool syllabus. On the other hand, several researchers, such as [49-51] only used available AR applications for young children available on the Internet in their studies.

Physical content design. Virtual content design refers to the multimedia elements used as overlays when users started scanning a marker. Essentially, all of the virtual contents consisted of five multimedia elements, namely text, image, audio, video, and animation.

Marker design. Another important aspect of AR applications is the design of markers. In general, there are two types of AR markers, namely the QR code marker and Image-based marker. Previously, the latter was based on two-dimensional (2D) programmed markers showing digital contents in either black and white or color tags [51]. Now, colored 2D images are used for the design of such markers. In this review, 11 out of 16 studies used image-based markers; in contrast, only four studies involved QR code markers. The remaining two studies did not provide any information about the type of markers used. Arguably, most of the researchers used image-based markers because such markers were more attractive compared to QR code markers consisting of square white and black boxes that were less appealing. According to [47], the visual richness and aesthetics of a marker are important to attract users' attention. They also assert that it is important to make a marker invisible, which can help increase users' imagination of AR applications as something magically appealing. On the other hand [51] assert that users can easily identify black-and-white markers, such as the QR code marker, more easily than colored image-based markers, arguing that the multiplicity of shades or similarities in colorful signs may render the mobile device's camera unable to identify such images correctly.

For easy recognition and tracking of markers, [39] recommended the use of large markers (such as 8 cm by 8 cm markers) and 0.5 cm white border. They also recommended the use of markers with a handle rather than markers printed on a flashcard or an AR book, as the former will ensure they will not be touched and covered by the children's hands. Such a recommendation seems reasonable as children will inevitably cover a marker that blocks a mobile device' camera from scanning, thus making them unable to launch the AR application. For optimal detection of a marker, [38] found that the distance between a camera and a marker was within 10 cm and 30 cm under normal condition.

3.2 Interface design

A well-designed interface is important for users to interact smoothly with AR learning applications. Essentially, the interface of an interactive system consists of several important components that provide information and control for the user to accomplish specific tasks [52]. Thus, an interface can affect a user in a variety of ways. If the design of an interface is confusing, users will have difficulties in completing a task at best or they may commit many mistakes at worst, thus making them frustrated and demotivated, respectively. Therefore, it is important to understand how to design a good interface for an AR application. In this review, only six studies by [37,41, 43-46] had information of the type of user interfaces used in such studies, which were essentially based on a simple design of AR interface.

For example, [46] divided their AR graphic user interface (GUI) into three main areas, namely display space, main button, and narration space. Such a design allows users to view a 3D model and animation in the display space. It also allows users to control the application by providing 'Start', 'Quit', and 'Refresh' buttons. In addition, users can use the narration space to listen to a story. Meanwhile, the interface of an AR application developed by [37] had a 3D model space, information space, and 'Rotation', 'Home', 'Exit', and 'Video' buttons. In addition to the above features, [43] AR application interface also had 'Play', 'Quit', and 'Back' buttons, while the interface designed by [44] consisted of a splash scene, loading, information page, and main page, with the last two features providing information on how to use the application and allowing them to navigate between pages, respectively.

3.3 Interaction design

Interaction can be defined as the communication between the user and computer that plays an important role in the overall user experience. For the AR technology, one way of interaction is by letting the user to view or to perceive the world from different perspectives. In addition to this basic interaction, the user may interact with the AR application by gestures, voice recognition (command), and a combination of actions. As highlighted in this review, AR applications used in previous studies mainly supported two types of interaction as follows: (1) interaction between a participant and an AR application, and (2) interaction between a participant and other participant.

Participant- AR application interaction. In this review, 77% of previous studies focused on the interaction design between users and AR applications. Based on the analysis, the interaction design of AR applications allowed users to view virtual objects by pointing and scanning techniques. In addition, the users could perform a few techniques, such as zooming and rotating virtual objects [49] which was accomplished by touching a digital screen by using his or her fingers, taking photos of virtual objects [50], and playing games, such as a jigsaw puzzle [24], which heightened the interaction between the user and the AR application. Such an interaction is called touchscreen interaction, which is one of the common interaction techniques used in AR games for children. In principle, this interaction allows users to select a particular item of interest by touching on the screen of a mobile device with their fingers. Thus, appropriately designed virtual contents can engender seamless interaction between the virtual and physical worlds.

On the other hand, a review conducted by [39] revealed that some AR applications used in previous studies supported multimodal interaction. Specifically, their study suggests that speech recognition will be a new interaction technique for AR learning applications. They found that speech recognition could help children complete their tasks faster with a greater sense of enjoyment. The same researchers also recommended that the arrangements or locations of AR makers should be such that children would be able to select them intuitively, as children (who are in general have a very short attention span) tend to miss markers during the learning process.

Participant- Participant(s) interaction. Several researchers did mention about the type of interaction involving children in their studies. They found that children enjoyed such an interaction that helped enhance their motivation. Such findings are hardly surprising as learning activities can be fun if children collaborate or work in a group [39]. In addition, the above findings are consistent with the research findings of [24] who found children were willing to take turns in sharing an AR application with one another. Likewise, the same consistency was observed in [40] finding that showed children willingly interacted with one another in completing an AR task on their iPads [50].

3.4 Imagination design

Interestingly, the review showed that some children viewed AR technology as some sort of a magical tool that enhanced their imagination, a factor that is also important in learning. For example, [48] found that children's liking for AR books was attributed to their perception of such materials as being magically appealing, with many animations appearing in such novel books. Compellingly, they were attracted by AR books because of the lively characters in such books that could 'talk' to them as well sense their presence.

Similarly, in the same year, [50] found animated virtual objects in AR applications could trigger children's imagination. In their study, children imitated various movements of a virtual airplane that helped improve their imagination, motivation, positive feelings, and motivation in learning [53]. Similar improvements were observed in a recent study by [40] who found Bangladeshi children were eagerly excited in exploring hidden objects in an AR book. Likewise, [39] observed that children were highly excited and motivated in learning when the latter felt like talking to a robot when an AR application responded verbally to their responses.

3.5 Immersion design

Immersion refers to how children perceive the degree of reality in a virtual environment through various sensorial engagements, including self-engagement, environmental engagement, and interactive engagement [35]. Interestingly, in this review, a study by [39] revealed that the size of displayed virtual objects had a major impact on immersion. They observed that children became highly immersed in learning when the sizes of virtual objects were close in relation to children's sizes. However, they cautioned that AR-based applications for young children should not be designed for full immersion because they may have difficulties to differentiate between the real and augmented environment, which may raise several issues relating to safety, security, and misconceptions.

4 Discussion

In this study, the researchers attempted to systematically analyze the current literature on the design of AR learning applications for young children. As reviewed, designing such applications will be quite challenging. Nonetheless, appropriate designs have to be put in place to ensure young children can use novel AR learning applications with greater ease and enjoyment. Overall, 16 articles relating to the design and development of AR learning applications were selected from two leading databases, which revealed five themes and nine subthemes as follows: (1) information design (with three subthemes), (2) interface design (with one subtheme), (3) interaction design (with two subthemes), (4) imagination (with two subthemes), and (5) immersion (with one theme). Table 3 summarizes the themes and subthemes of the design of AR applications for young children.

Table 3. The themes and subthemes of the design of AR applications for young children

Main theme	Subtheme	Recommendation
Information Design	Physical Content Design	The AR design for learning purposes must use educational-related content. The contents must be appropriately designed based on young children's' age.
	Virtual Content Design	The design of virtual contents (overlays) must use multimedia elements.

	Marker Design	Use 2D colorful images to attract young children's attention. Marker must be invisible to increase children's level of imagination. Used large markers with a border of 0.5 cm on each side. Design markers with a handle to prevent children's fingers or hands from blocking images. Set distances between markers within a 10-30 cm margin for easy marker detection.
Interface Design	User interface	AR applications must be designed with a simple user interface.
Interaction Design	Participant- application interaction	Point, scan, rotation, zooming, photo-taking, and games can increase children's level of interaction. Use multimodal interaction to achieve a high level of interaction, such as voice recognition as an input. Arrange makers that can facilitate easy selection (scanning) and design activities that can make children remain alert during the learning process.
	Participant-participant(s) interaction	Design activities that involve more than two participants to enhance children's sense of enjoyment and motivation.
Imagination Design	Animated virtual objects	Use animated virtual objects to increase young children's imagination.
	Characters	Use design characters that can respond verbally (using audios) such that children can feel they are talking with such characters during the learning process.
Immersion Design	Display size	Use large displays to immerse young children in AR applications

5 Future works

The findings of this systematic review can be used as a guideline for other researchers to conduct more in-depth studies relating to the impact of new designs of AR learning applications on young children's learning from the emotional, cognitive, and motivational aspects. In addition, future studies can use other types of databases to retrieve more articles regarding the AR design for young children.

6 Conclusion

The systematic review of the current literature of augmented reality (AR) technology revealed the imperative of designing an appropriate design for AR learning applications for young children. As highlighted, five main themes (with nine subthemes) emerged from the review of 16 selected articles relating to the design of such applications, namely information design, interface design, interaction design, immersion design, and imagination design. As such, all five themes related to the design aspects of AR learning applications need to be carefully addressed and taken into account in developing efficacious AR learning applications for young children.

Overall, the findings of this study based on the systematic review of the current AR literature can be used a guideline for developers of AR learning applications in all domain or subjects as long as it is focusing on the AR app development for early childhood education. This finding also can be used as a guideline for developers in order to ensure their products development can be both efficacious and entertaining, the impact of which can surely improve children's learning performance, motivation, and interest.

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