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ORIGINAL PAPER

An augmented reality PQRST based method to improve self-learning skills for preschool autistic children

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Abstract

Augmented reality (AR) technology is playing an important role in the preschool education. AR provides cost-effective learning systems which improve the attention skills of preschool children. In AR technology, the marker is used as an open-source computer tracking object to create AR applications that overlay virtual imagery on the physical world. Therefore, through augmented reality (AR) technology, learning materials, and knowledge can be visualized, and preschool children can learn interactively with the virtual model in an enjoyable manner and provide a stress-free teaching environment. This paper presents an ABCD AR Game for autistic children to learn the English alphabet innovatively. In the proposed system, a simple marker is used to recognize each character of the English alphabet to teach autistic children. After marker recognition, the ABCD AR-Game displays the corresponding image, helping students understand of English alphabets and their pronunciation, that provides multi-level gaming for reading, speaking, coloring, and writing under the teacher's and parent's supervision. The proposed system also provides game-based learning such as preview, question, read, self-recite, and test (PQRST) statistical method to optimize autistic children's reading and learning of English alphabets. For evaluations, seventy-two (72) autistic children, their parents, and ten teachers participated and were divided into two groups for the assessment. Evaluation results indicated that autistic children, parents, and teachers reacted positively to the ABCD AR-Game. These results showed that ABCD AR-Game enhances autistic children's learning and their motivation to learn about the English alphabet.

Keywords Augmented reality · Alphabet learning · Effective pre-school learning · Game-based learning · PQRST

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1 Introduction

Learning is a continuous process that never ends. It begins with childhood and ends with death. Early childhood growth and development play an important role in determining the future of one's life. The childhood period is the golden age concerning a child's growth and development. During this period, children can absorb knowledge very well, and they will be taught a variety of things, including learning about letters of the alphabet so they can read and write in the future. Still, the traditional educational system is not many engaging children for better learning. It is stated that students' engagement is decreasing each year because of the traditional learning modes (Jason 2017) due to technological modes highly influencing alpha generation (children born between 2010 to 2025). Therefore, integrating technology into traditional learning can boost children's engagement and learning results.

Augmented Reality (AR) and the use of digital games have gained interest among the scientific community, and

many studies have reported their advantages for learning purposes (Bacca Acosta et al. 2014; Bitter and Corral 2014; Diegmann et al. 2015; Hwang and Wu 2012; Klopfer et al. 2009; Tsai and Fan 2013). AR is a technology that can merge virtual information with the physical world in real-time, generating a whole new learning environment. Researchers must explore how AR technology can influence children's learning in future technology applied in education. AR has shown to be beneficial in fostering motivation, engagement, creativity, imagination, and collaboration (Diegmann et al. 2015). As a result, many researchers have developed augmented reality applications with educational content for effective learning.

On the other hand, games have gained particular interest since the beginning of the last decade. Game-based learning has grown (Tsai and Fan 2013), and several research articles proved the advantages of game-based learning (Hwang and Wu 2012). Games are considered exceptional, mind-changing, and effective tools in the classroom. Researchers argued their advantages in the learning process (Squire and Jan 2007), increasing effectiveness in the learning process (Merchant et al. 2014), improving learning outcomes (Abualigah et al. (2022, 2021)), motivating and helping to learn from failures, encouraging competition and collaboration (Klopfer et al. 2009). Therefore, integrating AR with Game-based learning would be the finest way for children to learn. These kinds of applications not only help students to learn effectively but also help teachers to deliver difficult concepts in an easy, fun learning way.

Based on the researcher's initial review and related literature, it was found that less research is conducted on integrating AR and Game-based models for kids learning. Most researchers do not include game elements such as the goal, fantasy, challenge, motivation, and interaction (social interaction). They focus on giving an immersive experience to users utilizing AR technology (Weng et al. 2020; Chen and Chan 2019; Ewais and Troyer 2019; Lam et al. 2020; Mokhtar et al. 2018; Lu and Liu 2015; Cieza and Lujan 2018; Rambli et al. 2013). The previous study combined the augmented reality and game concepts such as Lu and Liu (2015), Cieza and Lujan (2018), Rambli et al. (2013), Chen et al. (2015, 2018), López-Faican and Jaen (2020), Bhadra et al. (2016) focus on delivering knowledge for better learning and memorizing. They usually focus on a single topic and try to deliver maximum knowledge about that topic. For instance, ABC3D worked on letters and object recognition (Bhadra et al. 2016). Quiver Vision focused on giving an immersive coloring experience to kids (Clark and Dünser 2012). We aimed to help out kids in learning the pronunciation of alphabets and their corresponding words along with improving their writing skills through the aid of worksheets. Coloring worksheets were also included to bring their creative colored 2D content to life. We also utilized parent's and teacher's interaction by providing them with an AR game interface as a medium. Therefore, parents and teachers can play their role toward better kids' learning. Further study of related literature reveals that no research is conducted on teacher and parent interaction through augmented reality game-based application for better kids learning (Cieza and Lujan 2018; Rambli et al. 2013; Chen et al. 2015, 2018; López-Faican and Jaen 2020). This study aimed to develop an Augmented Reality Game-based application named "ABCD AR-Game" for children to learn alphabets and evaluate their knowledge and attitude towards the developed AR game-based application (Rambli et al. 2013). They also take more interest in visual-based learning materials such as colors, images, gifts, surprises, and animations (Lu and Liu 2015). Therefore, game-based learning enhances kids' interest in learning and gaining knowledge. For example, they can learn how to pronounce, write, and much more about basic learning such as alphabets (Chen et al. 2015).

In this paper, we propose a markers-based mobile application that provides an AR-Game (ABCD AR-Game) for autistic kids to learn English alphabets. The proposed system also provides PQRST (preview, question, read, self-recite, and test) method (Malia et al. 2015) for optimizing autistic kids' reading and learning English alphabets. The proposed ABCD AR-Game engages autistic kids in a fun-based learning environment to jog their fantasy and creativity. Seventy-two individuals were divided into two stratified factions to adequately assess the procedure. A comparison is made between the recommended technique (ABCD AR-Game) and the formal learning method utilizing an English alphabetical textbook. Subsequently, subjective surveys are used to assess the suggested procedure. The findings demonstrated how beneficial the suggested ABCD AR-Game is for autistic children learning the English alphabet.

The rest of the structure of this article is as follows. Section 2 presents a background study related to AR in education. Section 3 presents the proposed ABCD AR-Game. Section 4 is about experiments and evaluation. Section 5 presents results and discussion. Finally, Sect. 6 provides conclusions and identifies the future direction.

2 Background study

This section explores augmented reality, game-based learning, and both technologies in education. The research discussed in this section shows the potential of AR and game attributes for learning. Teaching children is a complex task without the use of technology. However, technology results surprisingly benefit learning, specifically in kids' education. Most researchers prove that the children's perspective of learning a concept through augmented reality is more effective than learning with conventional methods. They perform

testing by comparing students' classrooms with and without AR, and most researchers admit the importance of AR in education (Lam et al. 2020; Gogula et al. 2015).

2.1 Augmented reality applications in education

One of the earliest well-known augmented reality applications developed with educational content is Magic Book, as shown in Fig. 1. It generates 3D scenes of the book. It allows students to interact with the real and virtual environment in real-time with the aid of glasses. In addition, it enables users to experience an immersive view (Billinghurst et al. 2001).

In augmented reality, many real-time coloring-based applications have been developed to engage children, bring their creativity into life, and prove effective for coloring activities. For example, Quiver Vision can change the colors of virtual models based on the colors of marker changes drawn by the user. It provides children with an enjoyable and engaging experience (Clark and Dünser 2012). Magic Toon is another creative augmented reality application developed in china. This application consists of two main parts: an interactive model editor to build more complex AR sceneries, and an automatic 2D to 3D cartoon model maker. The model maker works with 3D models, duplicating and animating AR context (Feng et al. 2017). Another augmented reality coloring application has been developed in Malaysia with some exciting features for kids. They proposed a framework with suitable specifications for creating the content so it can be reusable to develop new coloring content integrated with a mobile application and highlighting issues that need to be solved (Mokhtar et al. 2018).

In the context of the English language and alphabet learning of children, several AR applications are proposed. For instance, to improve kids' literacy in early childhood, augmented reality technology is being used in California with the name ABC3D. This augmented reality mobile game harnesses the motivating power of interest and the affordances of augmented reality to engage children in practicing print-based literacy (Bhadra et al. 2016). AR application in teaching vowels and numbers to children has been reported to increase academic performance by 1.38 points for vowels, and 1.13 points for numbers compared to traditional learning (Cieza and Lujan 2018). Another AR application has been shown through the interactions of voice, graphics, and real-world environments. Students can learn the common vocabulary of each English letter and then discuss the impact on learning motivation, and effectiveness (Chen et al. 2018). A typical design in AR applications that utilizes AR flashcards can also improve vocabulary in kindergartens. Participants showed their positive attitude towards augmented reality flashcards for learning purposes (Chen and Chan 2019). An educational magic toy (EMT) mobile application has been developed. It consists of fruitful virtual learning content such as story animations, 3D objects, and flash animations that appear on the toys. EMT used puzzles, flashcards, and match cards to teach animals, fruits, vegetables, vehicles, objects, professions, colors, numbers, and shapes for Early Childhood Education. Teachers and children showed a high positive attitude towards EMT (Yilmaz 2016). Meanwhile, augmented reality also proves it is effective for science topics. For example, an augmented reality application was developed to learn about fish habitats. This application introduces Taiwan's marine ecology and water resources to primary school students, making learning fun and exciting (Lu and Liu 2015). An augmented reality game has been developed in Taiwan to deliver knowledge about ocean life

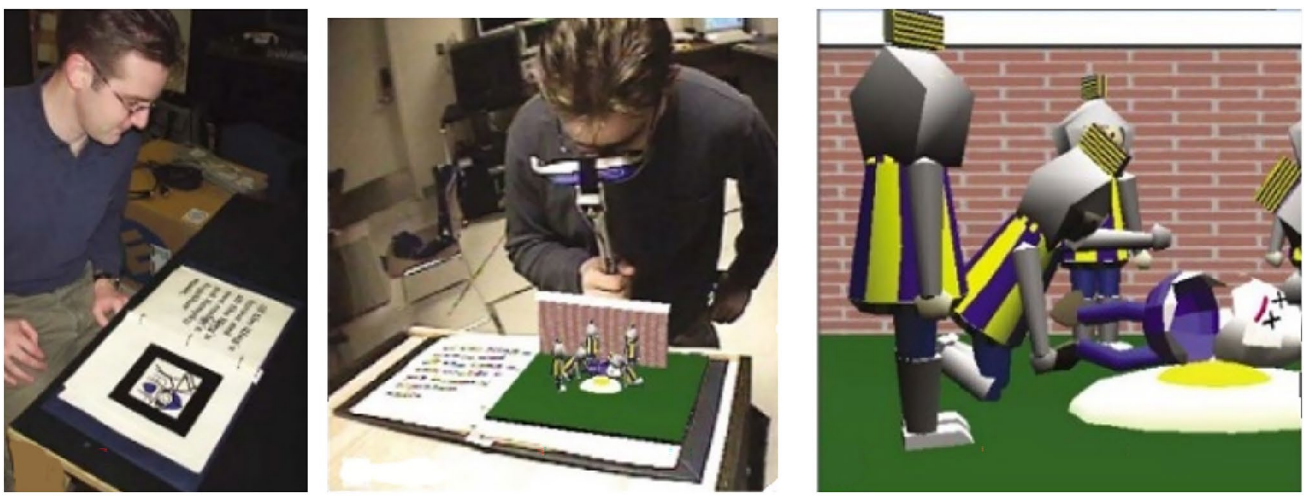

Fig. 1 Magic book **a** marker, **b** visualization of Virtual content, **c** virtual content (Billinghurst et al. 2001)

and food chains in the ocean. The learning system has two main pages: the fishing page and the food-chain page. Learners must complete the tasks on the first page before proceeding to the next page for effective learning (Chen et al. 2015).

2.2 Game-based learning

In education and pre-school learning, game-based learning is gaining more and more attention. Game-based understanding means applying some game attributes to a non-game learning situation. Therefore, the use of games and game structures in educational contexts is gaining popularity. Fantasy elements characterize game-based learning to motivate students to learn better. Game attributes are features and characteristics inherent in its structure and are likely to initiate and maintain interest in gaming activities. The study reveals that the game-based learning model has numerous attributes including assessment, achievement, story content, rules, competition, problem-solving, engagement, emotions, scores (points), motivation, collaboration (teamwork), visual aesthetics, fantasy, challenge, interaction, and goal (Alaswad and Nadolny 2015). Figure 2 shows the frequency of game-based learning attributes.

Many researchers have proved that students are highly interested in the game-based learning approach. The degree of involvement, motivation, and interest of students is increased by game-based learning, and they feel joyfulness in learning, due to which learning outcomes also increase. In game-based learning, students can develop skills like collaboration, communication, creative thinking, etc., and can also enhance the process of gaining knowledge and memorizing new concepts effectively (Liu et al. 2020).

2.3 Integration of game-based environment with augmented reality for learning

Many systems have combined both augmented reality (AR) and game-based environments to improve the learning ability of children. An educational augmented reality application is developed for kids' alphabet learning in Florida. It has game-based nature for learning with enjoyment (Salman and Antonius 2017). Reference (Tobar-Muñoz et al. 2017) adopted the augmented reality game-based approach to improving children's reading comprehension skills. The result reports that AR provides children with a new, fun learning experience. Other than that, children's reading comprehension and soft skills are also improved. Meanwhile, a puzzle AR game revolves around the character Dude, who lives in a Rainbow, and is always willing to help others and challenge difficulties. This game improves cognitive skills and allows traits of children. This game combines AR to convert traditional games into 3D holographic games, and the interaction between players and games is rich. At the same time, it also exercises the children's reactivity, and concentration (Wu et al. 2019).

AR game-based applications provide joyful, motivating, and engaging learning environments for students to improve their knowledge and learning ability (Chen et al. 2015). Using AR applications increases students' learning achievements, especially since they help weak students gain knowledge and memorize new concepts. During the research experiment, high motivation was one of the important observations among students, especially in children, (Chen et al. 2018; Bhadra et al. 2016). Augmented Reality and game-based learning have gained interest in the scientific

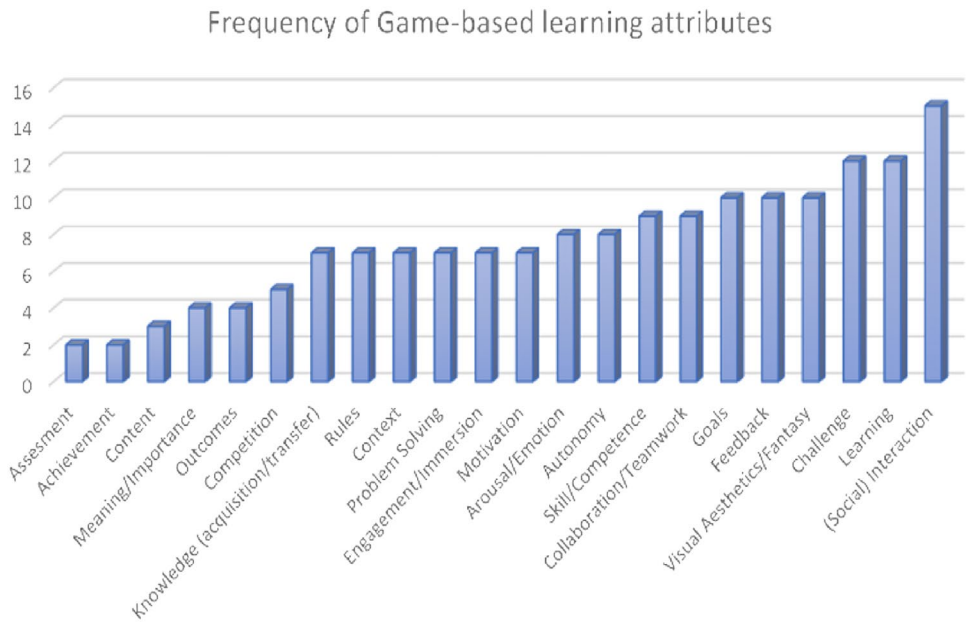

Fig. 2 Frequency of game-based Learning attributes (Alaswad and Nadolny 2015)

community (Wu et al. 2019). Researchers approved that learning with augmented Reality increases a child's motivation, engagement, creativity, imagination, and collaboration. They also believe game-based learning improves students' mental and physical health, increases the effectiveness of learning sessions and outcomes, and increases competition and collaboration (Tobar-Muñoz et al. 2017). Many studies prove that game-playing contributes to self-affirmation and the development of cognitive structures (Tobar-Muñoz et al. 2017). The game adds a playfulness layer to the augmented reality system, which generates good results for the learning kids.

The existing systems are efficient and play an essential role in preschool education. They also provide cost-effective systems for the learning ability of preschool children. However, most existing systems lack visual information that delivers complex and unrealistic interfaces which affects the exploration of the alphabet, interest, and learning process of students (Ali et al. (2022)). To provide simple-in-use and necessary realistic information about any English alphabet, we developed ABCD AR-Game for autistic children to guide them in learning English alphabets. In the proposed system, we integrated both augmented reality (AR) and a Game-based environment to assess the autistic children in learning English alphabets along with corresponding virtual objects/contents. Using a mobile camera, it uses markers to visualize virtual objects/contents about the English alphabet. After marker recognition, the ABCD AR-Game displays the corresponding image, assists students in understanding English alphabets and pronunciation, and provides multi-level gaming for reading, speaking, coloring, and writing under the teacher's and parent's supervision. In the proposed system, an interface combining real and virtual objects with game attributes acts as a natural attention grabber for autistic children. Through the proposed system, their facial expressions exhibit enjoyment while learning the English alphabet.

3 Proposed ABCD AR-Game

This section presents the architecture of ABCD AR-Game with the help of visual aids. Moreover, the evaluation shows the user's attitude towards the ABCD AR game. The proposed ABCD AR-Game provides the following advantages over the existing AR-based learning systems:

- ABCD AR-Game encourages children towards learning.
- ABCD AR-Game seeks children's attention. Children's involvement in learning activities is increased by using game attributes with AR.
- ABCD AR-Game allows children to visualize virtual content and to bring their creativity to life.
- ABCD AR-Game helps children to learn and memorize alphabets.
- ABCD AR-Game helps teachers and parents to teach their children in an innovative, fun learning way.

3.1 Architecture for the development of AR game

This section explores the architecture of the system with the its essential components. Figure 3 depicts the system architecture of the ABCD AR-Game. The users install apk (android application package) file on the mobile device. Application triggers the camera of the mobile device to focus the camera on the AR. The device calculates the pose and augments the 3D model on the mobile screen, as shown in Fig. 3).

3.2 Game and marker design

We developed an Augmented Reality game (ABCD AR-Game) using Unity and Vuforia. It is all about kids learning. This Application will teach alphabets and their phonics with the help of fruits, animals, and non-living object names. The game will also prove a better option for practicing reading, writing, and coloring activities. Finally, the game allows parents and teachers to supervise properly to kids by its different modules for better results.

ABCD AR-Game visualizes interactive AR content in a 3-dimensional way along with the audio. As children scan the markers, they can view virtual content, listen to different audio pronunciations, and interact with virtual content in 6 Degree of Freedom. These all virtual content are according to the markers. For example, when children scan the Apple marker, a 3D apple will be visualized on a mobile screen, and audio starts playing, which is "A for Apple", 10 points will be given after a few seconds of successful visualization. In this way, children can scan all markers from A to Z, visualize and listen to their virtual content and get points (see Fig. 4).

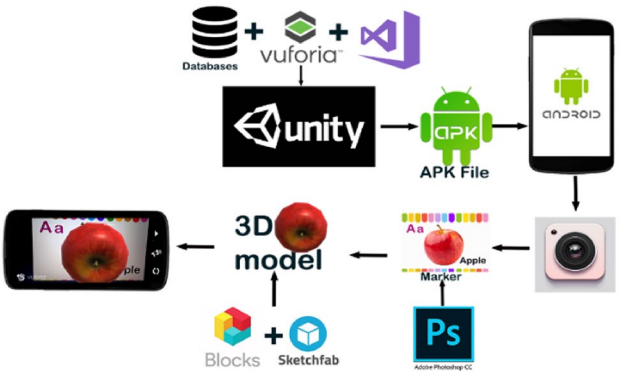

Fig. 3 Architecture for development of ABCD AR-Game

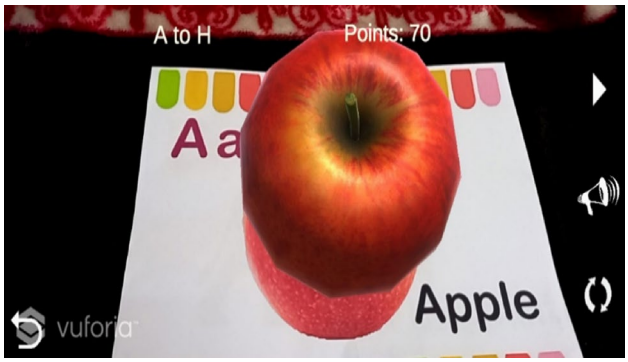

Fig. 4 Visualization of 3D apple on apple marker

The game is divided into five categories: Read, Speak, Write, Color, and Quiz. All these categories have sub-levels. 1st level of all five categories is unlocked, while others are locked at the beginning. Sub-levels will be unlocked when children earn maximum points in the previous level. It can also be unlocked by sending a request from the parent to teachers for a specific level of any category. Teachers have the right to accept or reject parents' requests. Markers of the "Quiz" category are designed according to the worksheet. Children complete the worksheets based on their creativity and can use the mobile AR application to visualize their written content and take screenshots. This screenshot is sent to their teacher so teachers can rate children's work. Points are given to children after the evaluation of a teacher. When the points reach this level's maximum, the next level is unlocked. Parents can check their child's progress based on the points earned by their child in different levels of any category, whereas teachers can also check their children's progress and activity sheets. Hence, the AR mobile game provides a medium of interaction between parents and teachers for better children's learning.

AR markers were designed using Adobe Photoshop CC 2019. The content of markers is according to kids' alphabet books that are used in educational institutes for kindergarten students to learn the alphabet. All five categories have different AR markers. For example, speak category has 26 Alphabet AR markers, the Write Category has three markers, while Read, Color, and Quiz categories have two markers. All Game Markers are shown in Fig. 5.

3.3 ABCD AR-game

A complete explanation of the game is presented in this section. The game has six modules, i.e., Registration, Play (has five Categories), Settings, Progress, Notifications, and Help for Parents. For Teachers, the game has four modules, i.e., Registration, Play, Progress, and Notifications.

The first module is for registration, and it is for the authentication of a user. Users can register by creating an account and logging on through username and password. This module is about the authentication and privacy of users' data. This module is for teachers and parents. This module provides parents' permission to their kids for game playing.

The menu Scene appears after the completion of Login. It has a further five modules for parents as shown in Fig. 6a and for teachers, there are three modules as shown in Fig. 6b.

The second module is about playing the game. For children playing, parents click on the Play button and select the category they want to teach their kids. The game has Read, Write, Color, Speak, and Quiz categories, as shown in Fig. 7a. As shown in Fig. 7b, these categories are further divided into sub-levels. In Read Category, kids can learn about Alphabets and how to pronounce letters. In Speak Category, kids can learn alphabet phonics from A to Z with the interactive 3D models, which show on top of the AR marker according to kids' alphabet learning content. In Write Category, a kid can learn writing skills with interactive videos and tracing worksheets. In Color Category, kids can color with AR markers and bring their coloring creativity to real life. Finally, in Quiz Category, the evaluation of kids is done with interactive augmented reality worksheets. Points will be given to the kids based on the time they spent visualizing and listening to AR content. These points are also displayed in the augmented reality playing mode, as shown in Fig. 7c and d.

The third module is about settings, as shown in Fig. 8a and b, where parents can send a request to the teacher to unlock specific levels in case previous level points are not appropriate for the next level, as shown in Fig. 8a. The teacher receives the request as notification from parents and responds to this request according to the child's progress, as shown in Fig. 8b. This module is for interaction between parents and teachers. Parents can download AR markers on which virtual content overlays through the setting module for a better learning experience.

The fourth module is about progress reports. Parents and teachers view the progress of the kid. Parents can view the progress of their children only. Meanwhile, teachers can view the progress report of all their students by their names. The progress scene for parents is shown in Fig. 9a, and for teachers is shown in Fig. 9b. These categories are designed according to PQRST (preview, question, read, self-recite, test) technique. Each reading level, Speak and Write, has visual aesthetics that gives preview(P) and raise questions(Q) in a kid's mind. Audio aesthetics motivate kids to read(R), speak, and self-recite(S) for what they are listening as shown in Fig. 9c. For Test(T), the Quiz category is designed where kids have to complete worksheets that act as a test for kids. In Color and Quiz categories, kids can capture screenshots after they have done

Fig. 5 Game markers **a** markers of speak category, **b**: markers of write category, **c** markers of color category, **d** markers of reading category, **e** markers of quiz category (Worksheets)

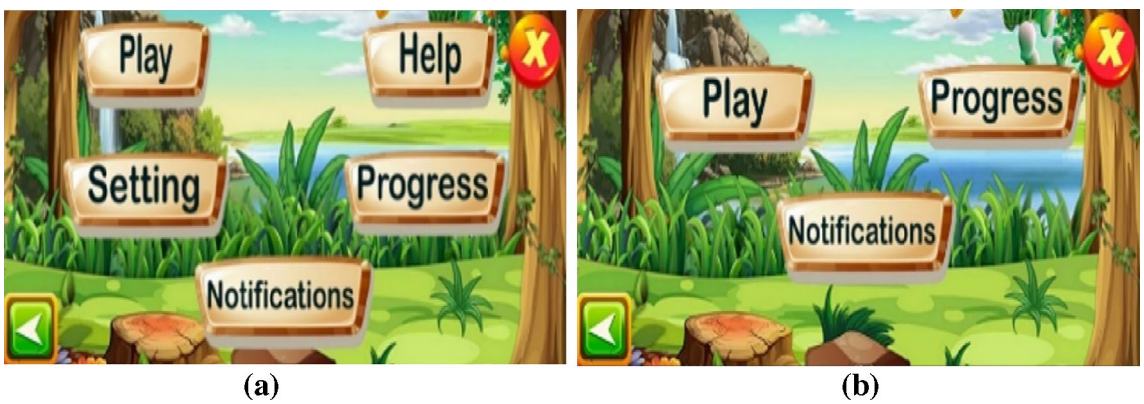

Fig. 6 Menu scene **a** for parents, **b** for teachers

Fig. 7 Play module **a** category selection scene, **b** level selection scene, **c** augmented reality playing mode, **d** capture screenshots of worksheets

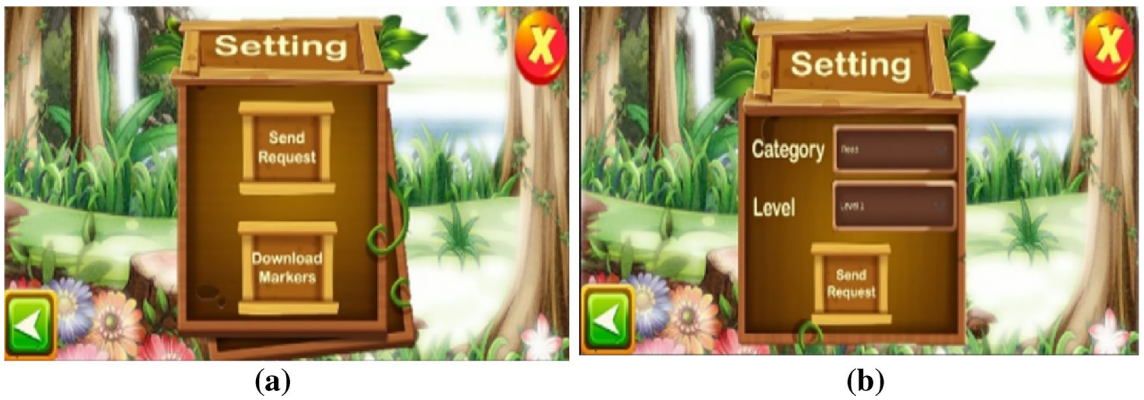

Fig. 8 Setting module **a** setting scene, **b** screen for sending a request

the worksheet, as shown in Fig. 9d, which goes to teacher notification (Give Points to User) and the teacher rate that kid's work based on the captured screen. These points are stored in a database and can also be seen through the progress module.

The fifth module, about notifications that show parents' requests to teachers, is shown in Fig. 10a, and the scene for teachers is shown in Fig. 10b. After that, teachers rate the sheets about children's kid's activity as shown in Fig. 10c, and the teacher's response to parents' request about unlocking a specific level is shown in Fig. 10d.

The sixth module is about helping to assist the users about different functionalities. The help button gives all necessary information to users as shown in Fig. 11a. First they can learn easily that how to send a request to unlock specific levels as shown in Fig. 11b. After unlocking now they can learn how to play this game as shown in Fig. 11c and d.

4 Experimental results and evaluation

This section is based on experiments and evaluation of the proposed ABCD AR-Game.

4.1 Experimental setup

The proposed ABCD AR-Game is developed in Unity 3D Engine 2018.4.12f1, Vuforia SDK 8.5.8 (for AR technology), Visual Studio 2017 (for back-end scripting), Microsoft SQL Server 2014 for storing user information, Adobe

Fig. 9 Progress module **a** for parents, **b** for teachers, **c** for Speak sub-levels (for both parents and teachers), **d** for color sub-levels (for both parents and teachers)

Fig. 10 Notification module **a** for parents, **b** for teachers, **c** for teachers to rate children activity sheets, **d** for teachers to respond to parents' request

Photoshop CC 2019 for markers development, Google Blocks and Sketckfab for 3D modeling. In addition, the SQL server database is integrated with WebAPI (built in Visual studio), and WebAPI is also integrated further with unity scripts. For comparison, the traditional textbook of basic English alphabets is also used to check the effectiveness of the proposed ABCD AR-Game.

4.2 Experimental protocol and procedure

For evaluations, seventy-two autistic children (42 males and 30 females), their parents, and ten pre-school teachers participated in the assessments. The ages of autistic children ranged from 4 to 7 years. To compare the proposed ABCD AR-Game, two groups were created from such

Fig. 11 Help module **a** first screen for help, **b** for "How to unlock level" , **c** and **d** For "How to play"

numbers of autistic children (i.e., G1 and G2). For proper comparison, G1 used the proposed ABCD AR-Game while G2 used the traditional basic English alphabetical textbook. For evaluation, all of them were invited and also briefed about the aim of this study. For each evaluation, the average duration was 30–40 min. The details of the evaluation are given below.

4.2.1 First activity

The first activity was to collect all the appropriate information about each participant, including children, their parents, and pre-school teachers. The background information consists of their gender and mobile games skill. As a result, 51% of them was no familiarity with computer/mobile games while 49% of them were experienced in such games. Most of them observed that it was a difficult task for them but they showed their self-confidence to perform the task.

4.2.2 Second activity

The second activity was a demonstration session to brief them (i.e., G1 and G2) about their corresponding tasks. The session took round about 25 min. We briefed participants of G1 about the different functions of ABCD AR-Game. Also, they were instructed how to download markers about each alphabet as a pattern using their mobiles. Similarly, G2 briefed about the basic English alphabet in their traditional textbook.

4.2.3 Third activity

The third activity was to perform both the groups their corresponding tasks. In G1, their parents created accounts in the proposed AR Game and downloaded different markers about the selected English alphabet. They gave their children their mobile phones, including markers, to perform the given task. The task was to select any English alphabet according to the suggested alphabet. The ABCD AR-Game displayed the image and pronunciation of the alphabet after recognizing the marker. The displayed image of the alphabet is selected so that its name starts with the character on the recognized marker, which helps students to learn the character with its pronunciation. The participants in G1 gained all the necessary information regarding the selected alphabets easily in the proposed ABCD AR-Game. Similarly, participants in G2 attained all the necessary information about the selected alphabets using a traditional textbook.

4.2.4 Fourth activity

The fourth activity was to conduct a verbal quiz from both G1 and G2 about the contents/course. Finally, each participant of G1 also completed a questionnaire to discover their emotions and feelings about ABCD AR-Game. Questions

are on 5 points Likert-scale with options of Strongly Disagree, Disagree, Neutral, Agree, and Strongly Agree.

5 Discussion

This section presents the analysis of the data recorded/collected during evaluations.

5.1 Assessing children's learning

In the first part of the analysis, a verbal test was conducted for G1 and G2 to judge the gained knowledge of individual children. The test covered different questions such as the pronunciation of characters, numbers in an alphabetical list, and recognition of virtual objects/contents with the corresponding symbol. Some of the questions are given in Table 1. The following are the learning conditions for both G1 and G2:

- G1 used the ABCD AR-Game.
- G2 used the English alphabets beginner textbook.

Comparing G1 (who used ABCD AR-Game) with G2 (who used traditional textbook), the significant difference is observed in their learning. The following formula (Equation 1) was utilized to measure the success of both groups:

$$SuccessRate = \frac{\text{Correct Answers}}{\text{Total Questions Asked}} \times 100 \quad (1)$$

Here the mean success rates of G1 was 74.33% (mean = 12.38 and standard deviation = 1.96), while that of G2 was 62.83% (mean = 10.47 and standard deviation = 1.72), as shown in Fig. 12 and Table 2.

To ascertain whether there is statistical proof that the associated means of the two groups are statistically substantially different, we also used the independent sample t-test as statistical evidence for significantly different results for both G1 and G2. The results of the independent sample t-test showed a significant difference between G1 and G2 in the achievements of their learning ($t(7.642) = 74, p = 0.000$).

Table 1 Verbally questions from children (G1 and G2) about various English alphabets

Q. No	Questions
1	What is the pronounciation of alphabet 'C'? (by dislaying C).
2	What is the number of alphabet 'H' in an alphabetical list?
3	What is the matching object/content related with alphabet 'B'?

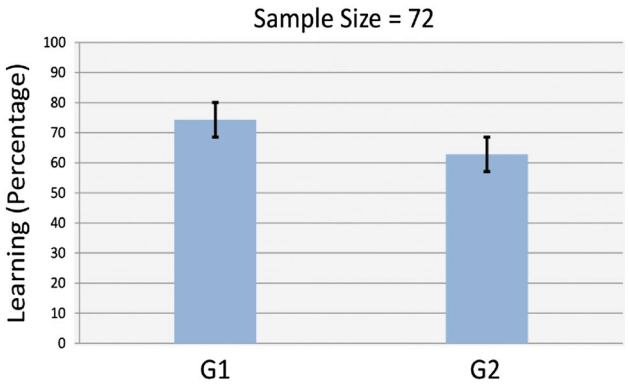

Fig. 12 G1 and G2 mean success rate with standard deviations

It can be concluded that the learning (success rate) of G1 is significantly better than G2.

5.2 Subjective evaluation

In the second part of the analysis, data were collected from the children, parents, and teachers through a questionnaire about the proposed ABCD AR-Game. The following questions from the G1 about different aspects, including easiness in learning, easiness in the understanding of interface, children's motivation, and their satisfaction with learning English alphabets, as shown in Table 3.

The following Table 4 summarizes of each autistic children feedback in G1 about ABCD AR-Game.

For parents and teachers, eight questions were designed, as shown in Table 5. Through these questions, we calculated the mean and standard deviation. As parents and teachers rate for the same type of questionnaires, we compared their results to know the positive attitude ratio of which user type is greater (more Strongly agreed answers). Mann Whitney test showed no significant difference in the attitude of parents and teachers. However, it has been considered a significant difference by means of values (i.e., more than 4.00) that parents and teachers felt the proposed ABCD AR-Game is more suitable for autistic children in learning the English alphabet. Table 6 shows attitude evaluation results of parents and teachers with the help of descriptive statistics. The overall results of the attitude evaluation of users were positive. Children like our unique interface because of its visual elements. Children enjoy ABCD AR games as well as this also

Table 2 Learning (success rate) of G1 and G2 (Participants = 72)

Group	Learning (%age)	Mean	Standard Deviation
G1	74.33	12.38	1.96
G2	62.83	10.47	1.72

Table 3 Questionnaire interview from autistic children in G1

Q. No	Questions
1	The proposed system is very suitable for children to enhance their learning about English alphabets.
2	The proposed system is very easy in understanding for children to enhance their learning about English alphabets.
3	The proposed system increases children's motivation for learning of English alphabets.
4	The interface is a trouble-free interface for children.
5	Overall, I am satisfied with the propose system.

Table 4 Responses of autistic children in G1 (Participants= 36)

Questions	Mean ± SD
Q1	4.83 ± 0.23
Q2	4.59 ± 0.82
Q3	4.91 ± 0.24
Q4	4.82 ± 0.72
Q5	4.76 ± 0.55

improves their learning. Parents and teachers also like the ABCD AR game and the medium of interaction it provides.

To conclude the above results, the learning (success rate) of students in G1 who used ABCD AR-Game was apparently better than that of G2 who used traditional English alphabetical textbooks. Similarly, we also found through subjective evaluations that participants in G1 were overall satisfied with various aspects of the proposed system. These aspects include easiness in reading and learning alphabets, easiness in the understanding of interface, and children's motivation and satisfaction for learning English alphabets. In addition, the parents and teachers also considered the proposed system suitable for autistic children in learning the English alphabet. They also considered that ABCD AR-Game is easier than traditional learning. All the autistic children also showed active participation during the evaluation. Overall results of the evaluation indicate the significance of the ABCD AR-Game in reading and learning the English alphabet and its ease of use.

6 Conclusion and future work

This paper presented an ABCD AR-Game for autistic children to learn the English alphabet. The proposed system uses a simple marker to recognize each character in the English alphabet to teach autistic children. The proposed system assesses students in understanding English alphabets and their pronunciation, providing multi-level gaming for reading, speaking, coloring, and writing under the teacher's and parent's supervision. The proposed system also offers game-based learning such as preview, question, read, self-recite, and test (PQRST) statistical methods to optimize autistic children's reading and learning of English alphabets. For evaluations, seventy-two (72) autistic children, their parents, and ten teachers participated and divided into two groups (i.e., G1 and G2) for the assessment. The students in G1 who used ABCD AR-Game were significantly better than G2 who used traditional English alphabets textbook. Similarly, a subjective questionnaire is also used to assess the recommended process. The outcomes demonstrated that the suggested ABCD AR-Game is better for demonstrating the English alphabet with its various aspects. These aspects create easiness in reading and learning alphabets, easiness in the understanding interface, children's motivation, and their satisfaction with learning English alphabets using the proposed ABCD AR-Game.

Table 5 Questionnaire interview from parents of G1 and teachers

Q. No	Questions
1	Playing in the proposed system provides a productive use of time for autistic children.
2	The proposed system is more helpful for autistic children to learn English alphabets as compared to traditional learning.
3	The proposed system is more useful to encourage autistic children for English alphabets as compared to traditional learning.
4	The size of Marker and its relative object/content are appropriate in using for autistic children.
5	The proposed system is very helpful for autistic children to memorize English alphabets easily.
6	The proposed system is very suiatble to improve the grades of autistic children.
7	The proposed system is more enjoyable as compared to traditional learning of English alphabets.
8	The proposed system is highly recommended in the learning of English alphabets.

Table 6 Parents' and Teachers' Responses (Parents= 30 and Teachers = 10)

Questions	Group of parents N = 36 Mean ± SD	Group of teachers N = 10 Mean ± SD	Mann Whitney test (U value and P value)
Q1	4.90 ± 0.30	4.80 ± 0.40	U = 135.0, P = 0.414
Q2	4.83 ± 0.45	4.30 ± 1.00	U = 107.5, P = 0.057
Q3	4.93 ± 0.25	4.60 ± 0.66	U = 122.0, P = 0.052
Q4	4.87 ± 0.43	4.30 ± 1.00	U = 103.5, P = 0.028
Q5	4.93 ± 0.25	4.80 ± 0.45	U = 125.0, P = 0.229
Q6	4.93 ± 0.25	4.80 ± 0.80	U = 130.0, P = 0.229
Q7	4.77 ± 0.41	4.60 ± 0.66	U = 134.5, P = 0.399
Q8	4.93 ± 0.25	4.90 ± 0.30	U = 145.0, P = 0.732

The proposed ABCD AR-Game is an effective system for autistic children. However, the proposed ABCD AR-Game also has some limitations, which require further improvement. For example, in the proposed system, users/instructors cannot add new virtual objects/contents about any character or add something new to its properties according to the autistic children's level. Therefore, one of our future works is to overlay more virtual content on AR markers, providing extra content to the corresponding character. Besides, in the proposed system, there is no voice recognition system to detect the children's voices about the pronunciation of each character. Hence, our second future work is to facilitate autistic children with a voice recognition system to detect their voice about the pronunciation of alphabets and improve their pronunciation accordingly.

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Data availability The authors confirm that the data supporting the findings of this study are available within the article.

Declarations

Conflict of interest The authors declare no conflict of interest.

Ethical approval All the techniques brought under use in the concerned study with the code of conduct and with the proper ethical standards of the institutional and national research committee.

Informed consent Informed consent was obtained from all individual articles included in the study.

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