Towards the Mixed-Reality Platform for the Learning of Children with Autism Spectrum Disorder (ASD): A Case Study in Qatar

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Towards the mixed-reality platform for the learning of children with autism spectrum disorder (ASD): A case study in Qatar

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Abstract. This virtual classroom has created a lot of challenges for students with limited access to the technology (computer or smartphone) or the Internet and especially for the parents of children with developmental disabilities, including children with autism spectrum disorder (ASD). ASD is a lifelong disorder and characterized by difficulties in social communication skills and may exhibit a restricted or repetitive set of behaviors. The number of children with ASD is soaring worldwide. There are no platforms that facilitate remote and interactive learning for children with ASD. In this paper, we describe the process of ideation, and design of an interactive educational platform that utilizes the role of mixed-reality (real-time teaching and virtual teaching) to enable remote learning for children with ASD. This work is a product of our continuous collaboration with special education and assistive technology centers based in Qatar in which we have developed an augmented reality (AR) vocabulary learning application for children with ASD in English and Arabic. The application provides the learning of letters and words in an interactive environment. We plan to extend this app to a full-educational platform using mixed-reality. The ideation and design processes were conducted collaboratively with teachers and specialists. In this platform, the child will be learning in a real-time environment when a teacher, child, and parents are all online together at a given time; however, in the absence of a teacher, a robotic talkative avatar would support a child and its parents in a virtual environment. The teachers will also have the capability to communicate with the children and their parents through the platform. It will also allow teachers, specialists, and parents to monitor the child's performance as well.

Keywords: autism spectrum disorder (ASD), Mobile augmented reality (AR), language comprehension, vocabulary, smartphone, tablet.

1 Introduction

The term *autistic psychopathology* was coined by the Austrian pediatrician Hans Asperger in 1938 in a lecture delivered in German (Asperger, 1944). In English, the term was first used by Leo Kanner at John Hopkins Hospital in the United States. He introduced the world *autism* that refers to a condition associated with significant impairment in social, linguistic, and cognitive skills. In his paper, Kanner (1948) described the symptoms that accompany autism. Since then, research has made great progress in better understanding the disorder and in providing suitable interventions. Today, autism is defined as being a spectrum disorder in which a set of different symptoms is apparent during childhood and continues into adulthood. The symptoms of ASD may vary in terms of behaviors and severity. These symptoms range from impaired social behavior to communication and language deficits. Repetitive behavior and difficulty in processing sensory inputs are often apparent (*Diagnostic and statistical manual of mental disorders [DSM-5®]*, 2013). According to the World Health Organization, 1 in 160 children in the world has ASD. However, they stress that this estimate varies substantially across the world (Elsabbagh et al., 2012). The United States reports an ASD prevalence rate of approximately 1 in 59 children (Baio et al., 2018). In Qatar, the Qatar Biomedical Research Institute recently revealed that ASD is prevalent in 1.14% or one in every 87 children (Alshaban et al., 2019). The causes of autism are attributed to both genetic and environmental factors (Landrigan, 2010; Lehmann & Murray, 2005).

To date, ASD is being clinically diagnosed through behavioral assessment. The treatment regime is tailored to the child's needs, and it usually consists of a set of different educational, behavioral, or medical interventions. The educational and behavioral interventions are the most studied and commonly used approaches with children with ASD. Over the years, a number of approaches were developed and used to address the challenges associated with ASD (Sandbank et al., 2020). These approaches differ in their theoretical background and execution methodology. Applied Behavior Analysis (ABA) has been effective in supporting children with ASD in their daily life (Sulzer-Azaroff & Mayer, 1977). Even though it has been used for quite a long time, questions have recently been raised about its effect on inclusive education (Shyman, 2016). Other common approaches to support communication and behavioral skills in children with ASD include the Picture Exchange Communication System (PECS) (Rubin, Prizant, Laurent, & Wetherby, 2013) and Social Communication, Emotional Regulation, and Transactional Support (SCERTS) (Rubin et al., 2013). The medical intervention consists of taking specific medication that helps with symptoms.

As a result of the need to support effective learning interventions for children with ASD, the researchers have explored different technological interventions including robotics (Shamsuddin, Yussof, Mohamed, Hanapiah, & Ainudin, 2015; Tapus et al., 2012), computer-based interventions (Aresti-Bartolome & Garcia-Zapirain, 2014; Fletcher-Watson, 2014; Khowaja & Salim, 2013; Khowaja, Salim, Asemi, Ghulamani, & Shah, 2019; Ramdoss et al., 2010; Ramdoss et al., 2012; Ramdoss et al., 2011; Silva, Da Fonseca, Esteves, & Deruelle, 2017), virtual reality (Didehbani, Allen, Kandalaft, Krawczyk, & Chapman, 2016; Lahiri, Bekele, Dohrmann, Warren, & Sarkar, 2015; Mesa-Gresa, Gil-Gómez, Lozano-Quilis, & Gil-Gómez, 2018), and Tangible Interfaces (Alessandrini, Loux, Serra, & Murray, 2016; Cullen & Metatla, 2019; Farr, Yuill, Harris, & Hinske, 2010; Karanya, Ajchara, Nopporn, & Patcharaporn, 2007; McGowan, Leplâtre, & McGregor, 2017) in order to support the needs of children with ASD. These interventions have been promising and successful in providing effective learning techniques by presenting the educational content in a form that is appealing to children with ASD. These technologies, however, have rarely supported vocabulary learning.

In recent years, augmented reality (AR) gained interest as a number of empirical-based research should its ability to attract ASD children's attention (Mesa-Gresa et al., 2018). Moreover, the research work in the applications of AR with children and adolescents with ASD has been increasing all around the world (Khowaja, Al-Thani, Banire, Salim, & Shah, 2019; Khowaja, Banire, et al., 2020). However, none have focused on online education and learning for children with ASD. In this research, we build on our previous research work (Khowaja, Al-Thani, Hassan, Shah, & Salim, 2020) which focused on designing and developing the initial prototype of a mobile augmented reality vocabulary learning application (MARVoc). The app supported vocabulary learning anytime and anywhere. In this work, we aim to enhance the novelty of MARVoc by incorporating the concept of mixed reality in an attempt to support online teaching and learning. Unlike typical students who can study and excel independently, children with ASD can benefit from the app by connecting with their teachers in real-time regularly and perform a set of tasks within the app environment. To the best of our knowledge, there is no educational platform that caters to the needs of children with ASD. The platform allows parents and teachers to view a child's performance, and teachers can create lesson plans according to the child's needs. The use of the AR app would benefit children with ASD as it would allow them to become independent individuals and live a better life. This paper presents the different stages of requirement, design, and evaluation. The paper focuses on the stages that involved users.

2 Method

The aim of this work is to develop, co-design, and evaluate a mixed reality platform for learning for children with ASD. To achieve this, we adopted human-centered empirical methods in conjunction with participatory design techniques (Muller & Kuhn, 1993). We have divided the project into three main stages which involved requirement gathering and evaluation. In all stages, we used semi-structured interviews and focus groups. However, the questions varied in each stage depending on the objective of the stage. Both semi-structured interviews and focus groups facilitated the generation of a multidisciplinary and variety of viewpoints to be discussed and explored. Our research team consists of two human-computer interaction (HCI) experts, three graduate students, and a software engineering expert. The interviews and focus groups included a group of practitioners that work closely with children with ASD. This group included speech and language therapists, special education teachers, assistive technology experts, and a psychiatrist.

For the analysis of the research of both the semi-structured interviews and focus groups, we adapted thematic analysis. Thematic analysis has been commonly used in the field of HCI (Brown & Stockman, 2013) as it is considered as a practical approach when exploring the perspectives of different participants in a particular field and an effective way to address commonalities whilst generating unanticipated insights. We used NVIVO 12 to help us synthesize the interviews and focus groups results. As illustrated in Fig. 1, the project started with the requirements gathering stage which was reported in (Khowaja, Al-Thani, et al., 2020). This stage shaped the development of MARVoc's first version (MARvoc V1). This stage was followed by an evaluation of the MARVoc V1 with teachers and practitioners. This stage resulted in modifying the first version of MARVoc and we were able to add more features that resulted in developing a mixed reality platform. Lastly, the research team was able to successfully evaluate the platform with the same experts which resulted in the MARVoc V2.1.

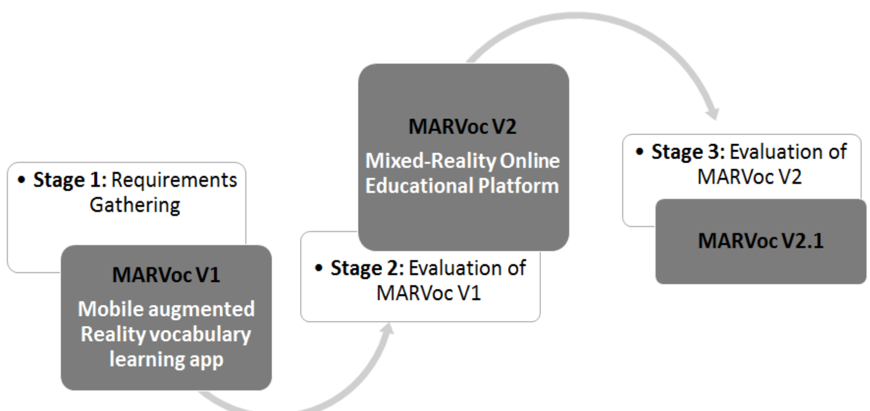

Fig. 1. Stages of the research

2.1 Stage 1: Requirement Gathering for MARVoc V1

Semi-structured interviews:

The semi-structured interviews were conducted with the teaching staff working at two centers located in Doha, Qatar to identify technologies used as a supporting tool for their classroom teaching, instruction methods used, instructional content taught, performance assessment, and the difficulties faced by the children with ASD. The two centers include the Step by Step Center for Special Needs where the English language is used as a mode of instruction, and Shafallah Center for Children with Special Needs where the Arabic language is used as a mode of instruction. Both centers are referred to as CENTER1 and CENTER2 respectively in the manuscript. The interviews conducted at CENTER1 were transcribed in the English language only, while, the interviews conducted at CENTER2 were transcribed in the Arabic language and then translated into the English language. The details of the semi-structured interviews can be read here (Khowaja, Al-Thani, et al., 2020).

Use cases development and selection

The needs of the teachers working at both centers were analyzed from the transcription of interviews conducted at CENTER1 and translation of interviews conducted at CENTER2. A total of two use cases were created based on the analysis of the needs. These use cases were discussed with the focal person working at both centers to reach a consensus about the selection of one use case. The use case selected after discussion with a focal person at both centers was about the learning of the English alphabet (uppercase and lowercase), construction of up to four-letter consonant, vowel, consonant (CVC) words, and construction of short phrases/sentences of up to four words. The details of the selected use case can be read here (Khowaja, Al-Thani, et al., 2020).

Functionalities.

The MARVoc provides children with ASD an opportunity to learn and take part in the activities. In the learning, children with ASD can learn mixed-mode letters of the English language, and those three-letter and four-letter CVC words which start with a vowel (‘a’, ‘e’, ‘i’, ‘o’, ‘u’) and have visual representation so that children with ASD can see the object and interact with it as well. The activities allow children with ASD to construct words three-letter or four-letter words randomly based on their own choice, or three-letter or four-letter words starting with, ending with, or contains any specific letter, The details of all the mentioned functionalities in the MARVoc V1 from the selected use case can be read here (Khowaja, Al-Thani, et al., 2020).

2.2 Stage 2: Evaluation of MARVoc V1

Stage 2 included evaluation of MARVoc V1 with teachers and language therapists. During stage 2, one focus group was conducted with 5 participants from CENTER1 in early January 2020 and semi-structured interviews were conducted with 10 special education teachers and speech and language therapists from CENTER2. The main themes that emerged from the interviews and focus groups can be illustrated in Fig. 2.

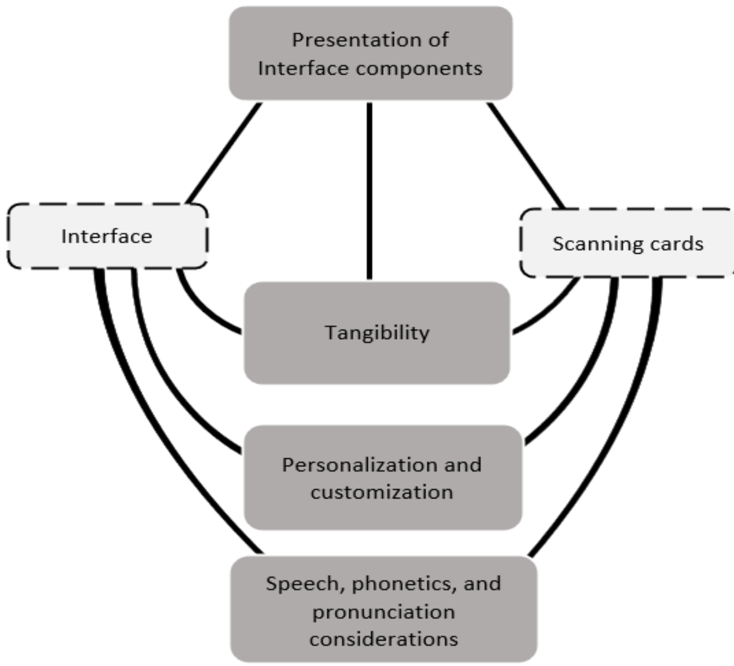

Fig. 2. Stage 2: Evaluation of MARVoc V1 thematic map

The main findings from stage 2 were revolving around the presentation of the app and usability recommendations for the autistic population. Direct quotes and recommendations related to the sub-themes: interface and scanning cards are shown in table 1.

Table 1. Interface components feedback

Interface related feedback	**Scanning cards related feedback**
Foreground and background color "The black background is also good as it doesn't cause distraction".	**Foreground and background color** "in general, the background should be simple and clear to avoid distraction".
Icons The icons are pretty small, the letters need to be maximized in size and visible so that the child can see them clearly".	**Texts and letters** "When scanning the letter, a relevant representative figure of the object int the card connected to that letter i.e. (A "ant", p "pot" …etc).
Text and font "The one we are familiar with, maybe Calibra or Arial. Yes, usually, these are the two interchangeably fonts we use".	**Font face and typeface** The one we are familiar with, maybe Calibra or Arial. Yes, usually, these are the two interchangeably fonts we use.

	Shape and size "Its fine, not too big neither too small, its fine".

The experts highlighted the use of card scanning for severe children with ASD is challenging. Research shows that children with ASD are frequently associated with motor malfunctions presented in fine, motor, and gross stability, postural stability deficit, gait, arm movement challenges (MacDonald, Lord, & Ulrich, 2014). In the interviews and focus groups, the participants argued that the scanning part of the app might be challenging for some students given that some students have motor limitations. The MARVoc requires series of fine and motor movements to scan the cards starting with placing the cards for scanning moving to the process of scanning the cards in order to get the AR representation of the vocabulary. The first version of the app did not incorporate any sort of sound or voice-over, which the experts easily pointed out to the research team and was successfully incorporated in MARVoc V2.

Functionalities of MARVoc V2

MARVoc V1 evolved into an educational platform that consisted of:

- Parent View, which includes a performance dashboard of their child(ren) interaction, list of teachers, list of children, access to child view and chat, and videoconferencing with teacher feature.
- Teacher view, which includes an add and remove parent feature, child's performance dashboard, chat, and videoconferencing with parent feature.
- Child view, which includes the functionalities of MARVoc V1. However, different modifications were applied. For example, different levels to support the learning of letters and CVC words were included, and the design of the cards to be scanned was also changed.

We also amended the application in terms of the look and feel of the different application components by applying the changes recommended by the participants. Educational games were added to support the engagement of children with ASD. A robotic-like virtual tutor was added to all screens to guide the child throughout the app.

2.3 Stage 3: Evaluation of MARVoc V2

In this stage, the intention was to evaluate the new enhancements. This stage included three focus group sessions. All of the participants have already participated in the evaluation sessions of stage 2, except for the one assistive technology specialist who was included in this stage. The first session involved one assistive technology specialist from Mada assistive technology Centre in Qatar, whereas the participants in session 2 involved 6 special education teachers, 3 speech and language therapists, and 2 other language therapists. Session 3 included speech and language therapists and one psychiatrist all from Center 2. Due to the COVID-19 pandemic, all the sessions were conducted remotely.

Fig. 3 illustrates the thematic map for the findings from the stage 3 evaluation. According to the research in the field of child-computer interaction, the primary goal for new interfaces for children is to be able to start exploring new technology with a minimal range of instruction (Hourcade, 2015). The reason being is that as children are less likely to engage in learning activities or receive instructions related to using technologies, the more likely they will learn and know technologies through exploration and play (Hourcade, 2015). Another significant finding that we had is related to the AR models used to represent a particular object. The experts highlighted that there should be a clear match between the models used in the interface and the real-life context for generalization purposes. They also highlighted that the technology should provide reasonable feedback in verbal and written form with the use of rewarding and gamification features.

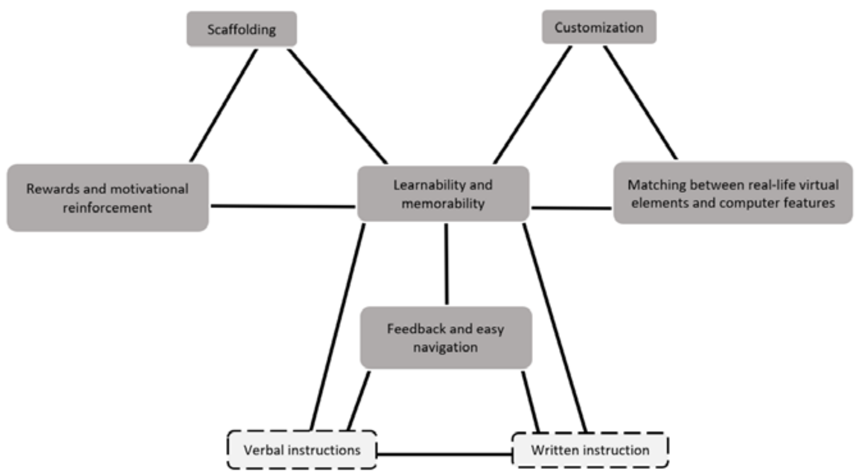

Fig. 3. Stage 3 evaluation of MARVoc V2 thematic map

3 MARVoc prototypes

3.1 MARVoc V1:

The screenshots of MARVoc V1 are shown in Fig. 4 and Fig. 5. The details of each screen can be read here (Khowaja, Al-Thani, et al., 2020).

Fig. 4. The first screen allows the user to choose an activity or learning. The second screen allows the user to choose to learn alphabets or CVC words. The third screen allows the user to choose an option to learn or take part in an activity (Khowaja, Al-Thani, et al., 2020).

Fig. 5. The fourth screen allows the user to select a letter to learn or for an activity. The fifth screen allows the user to construct a three-letter CVC word as a part of the learning or activity. The sixth screen shows an example of a marker used in the MARVoc (Khowaja, Al-Thani, et al., 2020)

3.2 MARVoc V2

Drastic changes have been incorporated into the new version of the app in terms of presentation as well as look and feel. As illustrated in Table 1, the new version is kept simple as instructed by the experts. The MARVoc V1 of the app incorporated warm colors which teachers described as "distracting" for a child with ASD as shown in Fig. 4 and Fig. 5. Therefore, ASD-friendly cool colors were used and new features were added to make the experience interactive and joyful for the child with ASD. A robotic avatar was designed to represent the application. As shown in Fig. 6, Marfooq is a new component in MARVoc V2 of the app which refers to and assembles kindness in the Arabic language. Marfooq as illustrated in Fig. 6 will help children with ASD learn vocabulary as it is supported with voice-over features. The robotic character was developed using ASD-friendly colors by a local designer to help the child learn and navigate through the app.

Fig. 6. The robotic character, avatar, and guide for children using the app. The robotic character is called "Marfooq" that will assist the user by providing instructions

Similar to MARVoc V1, the home page components remind the same, but the names were changed to "Learning and Activity" instead of "Activity and Training". The left-side of Fig. 7 shows the home page screens which allows the user to choose learning or activity. The "Activity" allows the child to choose one of three types of activities including creating a word that "Starts with" a certain letter or creating a word that "Ends with" a chosen letter. Lastly, generating a word that "Contains" a letter. All the screens in the app demonstrate the robot, Marfooq which will help children and provide them with verbal instructions.

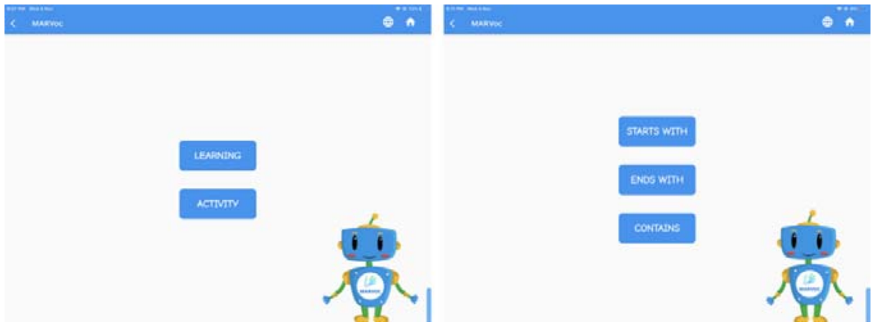

Fig. 7. The screen on the left allows the user to choose learning or activity. The screen on the right allows the user to choose the different activity types, such as starts with, ends with, and contains a letter. Both screens show the robot, Marfooq

Fig. 8 is an essential upgrade for our application which transformed our application into a mixed-reality platform. An interactive dashboard was added to emphasize inclusivity for parents and teachers of children with ASD during the critical times of the 2020 global pandemic. The dashboard was designed as a communication platform for teachers and parents to monitor the child's progress and to assess the vocabulary learning pattern for their children. There is a live-chatting and scoring log measuring the number of attempts and misses for the child as well as a duration record (in minutes) for how long the child spent in each activity.

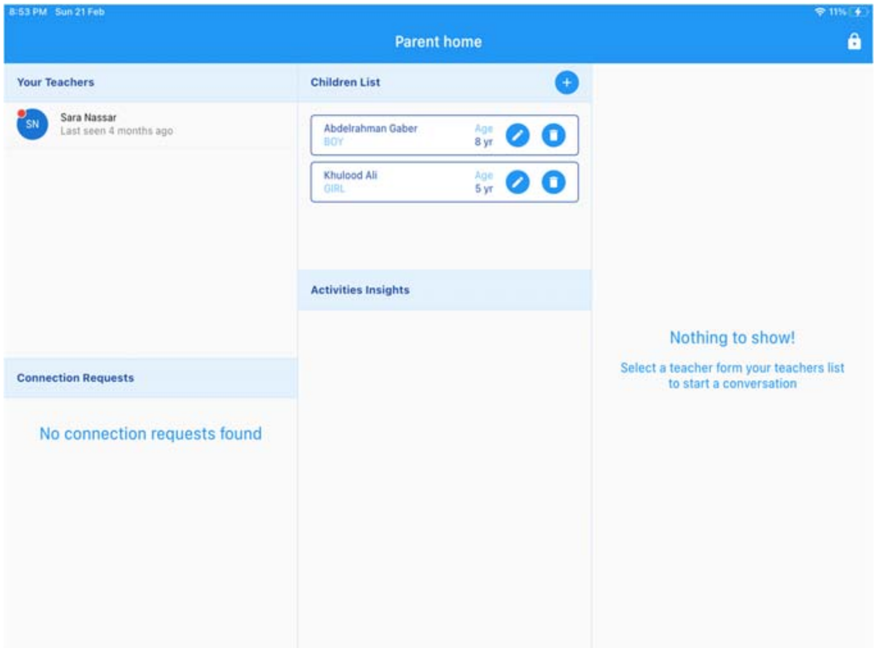

Fig. 8. The screen shows the dashboard of a parent. On the left column, the user can see the list of teachers that can be selected to communicate with. The user can see a list of their children along with activities they have completed in the column shown in the center. On the right column, the user can chat with a teacher by sending text or voice messages

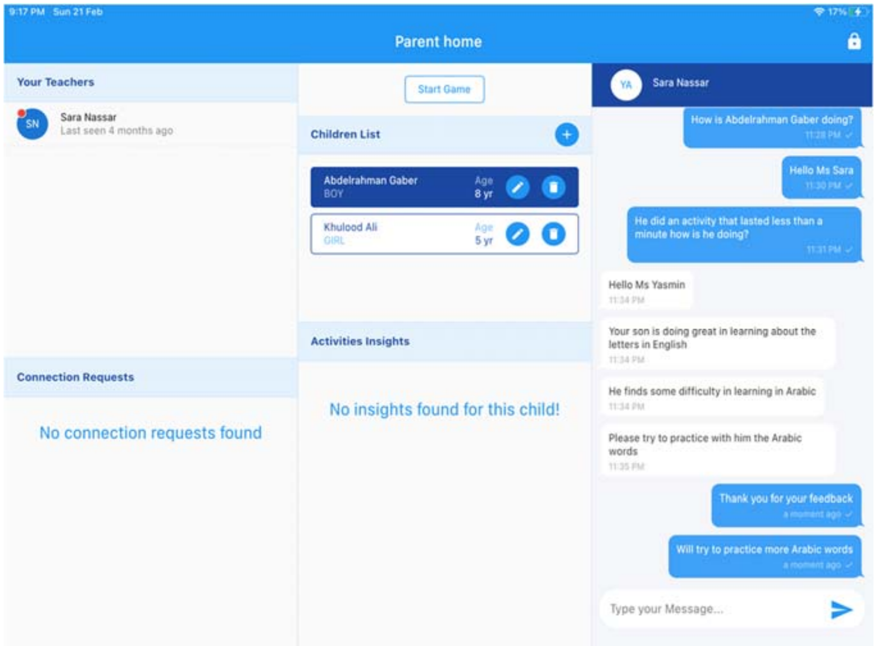

Fig. 9. The screen shows the dashboard of a parent. The format of this figure is same as of format of Fig. 8

The vocabulary learning and the augmented reality screens are shown in Fig. 10. The scanning cards are illustrated on the right side in Fig. 10. The child will need to use the back camera of the iPad to scan the letter to form a three-letter-word; or use the keyboard as shown on the left side of Fig. 10.

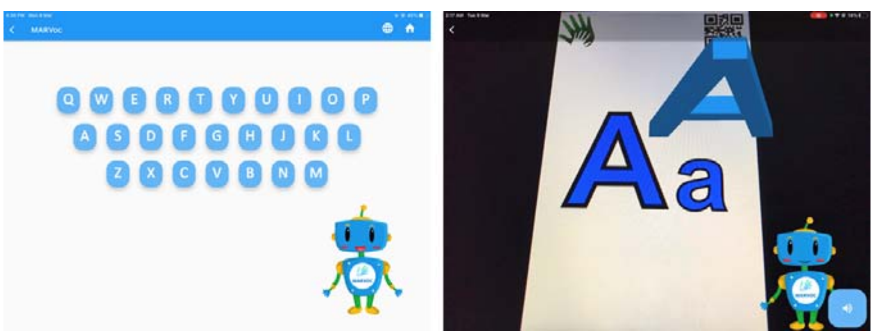

Fig. 10. The screen on the left allows the user to select any letter to learn. The screen on the right shows positioning a marker in front of the camera, the letter is then augmented

Fig. 11 is an example of a three-letter word. Fig. 11 shows the AR models used to represent a three-letter-word and demonstrates the essence of vocabulary learning. As the child progresses in learning, various levels of hints will be demonstrated to help the child master learning words to move to a more advanced level.

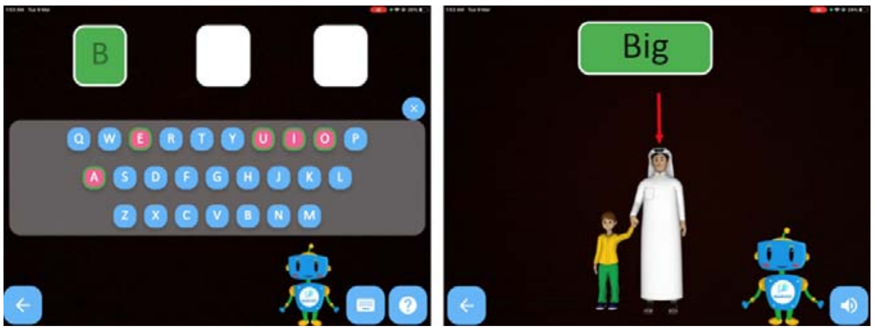

Fig. 11. The screen on the left allows the user to construct three-letter CVC words by dragging a letter into the right location. The screen on the right shows the AR model in 3D once the user constructs the word "Big". The user can listen to the pronunciation of the word.

Fig. 12 and Fig. 13 illustrates two types of games added to the new version of the app which was added to the app as a suggestion from the experts in the interviews to add entertainment or games to our platform. The first game as shown in Fig. 12 is called "what am I feeling?" which is aimed to engage the child and communicate their feelings using flip cards that assemble one feeling at a time. Whilst Fig. 13 represents another game in the app called "know my colors" which is aimed to engage the child by corresponding and recognizing colors. Both of the games have voice-over or text-to-speech which the child can click on; hear and follow instructions. This approach was not available in version 1 of the app and it was developed based on the recommendations outlined in the thematic map in stage 2 Evaluation of MARVoc V1.

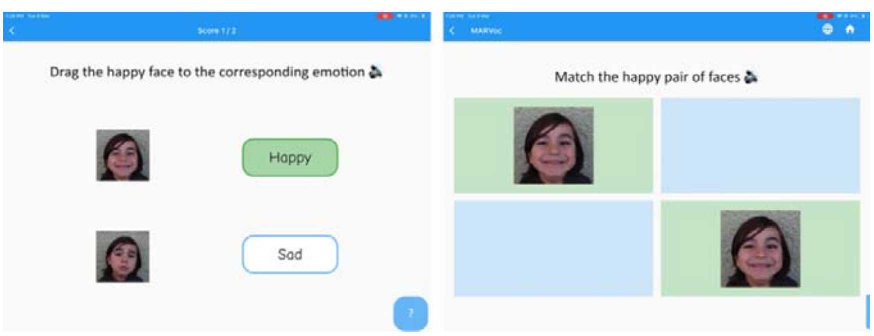

Fig. 12. The screen of the left allows the user to drag the emotion to its name. The screen on the right allows the user to match the correct set of cards representing emotions

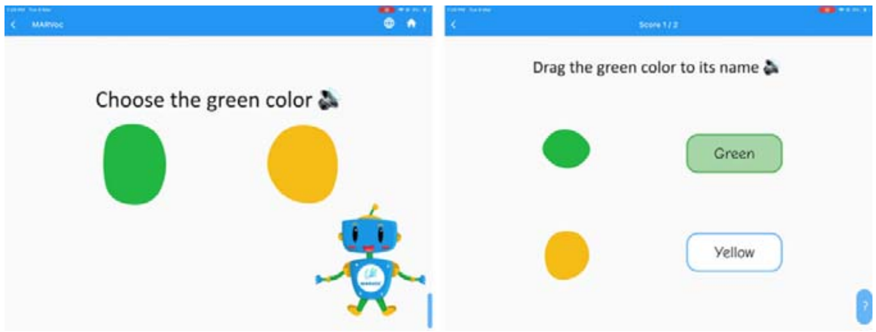

Fig. 13. The screen allows the user to drag the color to its name. The eleventh screen allows the user to select the correct color

4 Conclusion

This paper presents the ideation, design, and evaluation of a mix-reality educational platform for children with ASD. The human-centered approach followed in this research has led to shaping the idea of this research project from merely building an augmented reality app to support vocabulary learning to designing a mixed-reality education platform. The paper presented three stages of design and evaluation. Stage 1 was mainly focused on the requirement gathering and defining the main functionality of the MARVoc application. Stage 2 involved conducting evaluation studies with users in an attempt to enrich the design and functionalities. This phase results in adding major functionalities such as the robotic-like tutor, the different stages of learning, and the specific views for each category of users. The final stage aims to evaluate MARVoc V2 to fine-tune it and prepare it for a longitude user study. The next stage of the project aims to conduct a single-subject design study with the ASD children, and their parents and teachers. A single-subject research design study involves repeated measures for the same participants to understand the individual's normal variability to evaluate the effect of the proposed intervention on children with ASD.

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