Mobile Augmented Reality App for Children with Autism Spectrum Disorder (ASD) to Learn Vocabulary (MARVoc): from the Requirement Gathering to its Initial Evaluation

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Abstract. The use of different technologies for the intervention of children with autism spectrum disorder (ASD) has increased over the year with the increase in the number of children diagnosed with ASD. In recent years, among the different technologies, the researchers have started to use the augmented reality (AR) to provide the intervention of different skills to children with ASD. The use of AR has many benefits, including ubiquity, minimally work with a camera, among others. Despite several benefits, AR has been underutilized for the vocabulary learning of children with ASD. This paper presents the initial version of the Mobile augmented reality app for children with autism spectrum disorder (ASD) to learn vocabulary (MARVoc). The purpose of developing MARVoc is to support teaching staff at the centers based in Doha, Qatar, to provide an interactive learning environment to children with ASD. The requirements of the MARVoc were gathered from two centers for ASD in Doha; two specific use cases were created from which one use case was finalized for the development of MARVoc. The initial version of the MARVoc was developed; the feedback was taken from the staff working at centers for ASD in Doha, and MARVoc was updated.

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

1 Introduction

The number of children diagnosed with autism spectrum disorder (ASD) has increased throughout the world in the recent past. ASD is a neurodevelopment disorder, and a child diagnosed with ASD may have an impairment in social communication skills or a repetitive or restricted set of behaviors (*American Psychiatric Association [APA],* ,

2013). According to the research conducted by Alshaban et al. (2019), the prevalence rate of ASD in Qatar among children aged between 5 and 12 years is 1.1%. This is an alarming situation as the earlier the child is diagnosed with ASD; the earlier an intervention can be planned. The research on the use of technology (computer, smartphone, tablet, etc.) based interventions (TBIs) has increased. This can be seen through several review papers that have been written in one decade (Aresti-Bartolome & Garcia-Zapirain, 2014; Boucenna et al., 2014; Chen, 2012; Diehl, Schmitt, Villano, & Crowell, 2012; Fletcher-Watson, 2014; Ibrahim & Alias, 2018; Kagohara et al., 2013; Khowaja, Al-Thani, Banire, Salim, & Shah, 2019; Khowaja et al., 2020; Khowaja & Salim, 2013; Khowaja, Salim, Asemi, Ghulamani, & Shah, 2019; Knight, McKissick, & Saunders, 2013; Lorenzo, Lledó, Arráez-Vera, & Lorenzo-Lledó, 2019; Marto, Almeida, & Gonçalves, 2019; Mesa-Gresa, Gil-Gómez, Lozano-Quilis, & Gil-Gómez, 2018; Pennisi et al., 2016; Ramdoss et al., 2012; Ramdoss et al., 2011; Tsikinas & Xinogalos, 2019; Zakari, Ma, & Simmons, 2014). The literature on ASD shows that children diagnosed with ASD face difficulties in interpreting the meaning of the text being read, and vocabulary plays a vital role (Khowaja & Salim, 2013). Despite its importance, it is least investigated by the researchers. Among TBIs for children with ASD, serious games have been highly used and provide an active learning environment (Khowaja, Salim, et al., 2019; Noor, Shahbodin, & Pee, 2012; Tsikinas & Xinogalos, 2019; Zakari et al., 2014). Children with ASD learn well visually (Hayes et al., 2010). Serious games provide an education of some content; this makes it different from typical games whose sole purpose is only entertainment. Designing a regular game is hard, so designing a serious game is even harder as the focus must be balanced between educational content and entertainment (Winn, 2008). Game designers need to learn frameworks or models to design serious games. Khowaja and Salim (2019) have developed a serious game design framework for the vocabulary learning of children with ASD. Although the framework is specialized, the components used are generic and typically found in most of the serious games. Researchers can use the framework to design, develop, and evaluate serious games for different skills related to children with ASD (Khowaja & Salim, 2018).

Each child with ASD is different, Bosseler and Massaro (2003) have suggested that each TBI should be tested with an individual to determine if the solution is feasible for an individual or not. One key issue is the generalization of skills learned through TBI to a natural environment with a different setting, stimuli, etc. Mineo, Ziegler, Gill, and Salkin (2009) found that children with ASD prefer to take the lead by assuming the role of someone and perform the given tasks. Taking this into consideration, the use of virtual reality (VR), augmented reality (AR), and mixed reality (MR) where an individual interacts with the technology at their own has increased (Khowaja, Salim, et al., 2019). While VR takes the user into the virtual world, AR augments the real world with information from the virtual world. The interaction with the VR world requires at least a specialized VR headset. At the same time, the use of AR applications can minimally work with the smartphone with a camera or any ordinary webcam as well. The use of mobile AR app (MARA) is expected to dominate the market by 2022 in comparison to VR (Merel, 2018). From the recent reviews on AR for ASD (Khowaja, Al-Thani, et al., 2019; Khowaja et al., 2020; Khowaja, Salim, et al., 2019; Marto et al., 2019), it was

found that the use AR has increased from the year 2010 onwards. The skills targeted in the studies for ASD include social skills, daily living skills, attention, cognitive skills, communication ability, etc. However, the potential of MARA has been underutilized to provide learning of vocabulary.

To the best of our knowledge, MARA would be first of its kind for the research community as well as the children with ASD in Qatar, their caregivers, and teaching staff working at centers for ASD in Qatar. The use of MARA among locals would allow them to become independent individuals and live a better life.

This research builds on the existing work conducted by the first and last authors. In the existing work, the first author developed a serious game prototype for the desktop application in Kuala Lumpur (KL) Malaysia. The requirements of the prototype were gathered from the center for ASD based in KL. The prototype provided learning of 209 vocabulary items among 11 categories (fruits, animals, birds, etc.) to children with ASD (Khowaja, 2017; Khowaja & Salim, 2018, 2019). The prototype was improved based on the feedback of the teaching staff and experts (Khowaja, Salim, & Asemi, 2015). The prototype was evaluated with five mild children with ASD, recruited from the same center in KL. The results showed improvement in the children from the baseline to the intervention and maintenance.

In this research, the MARA prototype (referred to as MARVoc throughout the manuscript) is used to provide vocabulary learning to children with ASD. The advantage of using MARVoc is its ubiquity, i.e., learning anything supported through an app, anytime, anywhere. The MARVoc can be installed on the tablet PCs, or smartphones that have cameras and support augmented reality application programming interface (API). The MARVoc can be used in different settings, including the classroom, home, or outdoor; the performance of the children can be monitored online by the parents and the caregivers. For any solution to be successful, it is essential to consider the needs of the users, the children with ASD living in Qatar, in the context of this research.

Considering the usefulness of MARVoc and its underutilization for the vocabulary learning among children with ASD, this paper presents a requirement gathering, an initial version of MARVoc prototype, and its evaluation with the teaching staff working at centers for ASD in Qatar.

2 Method

A mixed-methods approach was used with the teaching staff working at centers for ASD in Doha, Qatar, providing to gather the needs of children with ASD. The semi-structured interviews were conducted with the teaching staff first. Then, the use cases were developed based on the requirements gathered from the teaching staff; these use cases were also modified based on the comments of the teaching staff. The concept of use cases was first introduced by the object-oriented community (Jacobson, Christerson, Jonsson, & Overgaard, 1992). This concept has been highly used in different fields, including human-computer interaction (HCI). In terms of the HCI, the focus is more on the interaction between the user (also known as an actor) and the system than the user's task only (Rogers, Sharp, & Preece, 2018). The use cases are easy to

develop and modify; the use cases can also be adapted and customized based on the needs of the users. The functionalities of MARVoc were created for the developers to develop an initial version of the prototype. The feedback on the initial version of the prototype was taken from the teaching staff working at two centers for ASD. The feedback from the teaching staff was provided to the developers to update the prototype. The details are described in the following sections.

2.1 Semi-structured interviews:

The purpose of conducting the qualitative study with the teaching staff was to identify: 1) technologies used, 2) instructional content taught, 3) performance assessment, 4) difficulties faced by the children, and 5) instruction methods used. For the study, two centers based in Doha, Qatar, were approached. These centers include Step by Step Center for Special Needs (referred to as CENTER1 in the manuscript) and Shafallah Center for Children with Special Needs (referred to as CENTER2 in the manuscript). The first two authors, the mainly second author, have been working with these two centers in the previous studies. Therefore, the heads of both centers know the researchers. The teaching staff and the students have also interacted with the researchers in earlier studies; thus, they know the researchers and are comfortable working with them. The heads of both centers were communicated to schedule a meeting to brief them at their respective centers about the project, and to take the consent to conduct the qualitative study to gather requirements with the teaching staff. In the meeting, the heads were informed about the purpose of the study. A detailed presentation on the project was also given. The heads, towards the end of the meeting, gave consent to conduct a qualitative study at their centers. A focal person was identified at each center with the help of heads for the main point of communication between researchers and teaching staff.

A total of 27 interviews were conducted at both centers. The interviews at CENTER1 were conducted in English as most of the staff working at the center were foreigners. In contrast, the interviews at CENTER2 were conducted in the Arabic language as the native language of most of the staff working at the center was Arabic. Before the start of the interview, each interviewee was given a consent form to read and sign. At the end of each interview, the staff was given a survey form to gather opinions in terms of difficulties faced, instruction methods, and strategies used based on a 5-points Likert scale (strongly disagree to strongly agree.) The interviews conducted in the English language were transcribed, while the interview conducted in the Arabic language were transcribed and then translated into English for the qualitative analysis.

Based on the needs' analysis from the transcription and translation, two cases were developed. The first use case was about the learning of letters and words, while the second use case was about learning of mathematical operations. Both use cases were discussed with the focal persons at both centers, and a mutual decision to choose the first use case was reached.

Based on the needs gathered, a MARA was designed to learn from uppercase and lowercase letters to four-letter consonant, vowel, consonant (CVC) words, and its pronunciation to the construction of short phrases for children with ASD of varying age.

For instance, the app can ask a user to form a word based on the picture shown. An uppercase and lowercase alphabet were printed on a card; each card acts as a marker. A marker in an AR is a visual cue that triggers the display of virtual information. When a marker is placed in front of the camera, it will show a 3D object augmented in a natural environment. A user can interact with a 3D object by scaling the size, rotating its shape to see an object from different angles, and hearing its pronunciation multiple times, among others. The app would record all the user's interaction with the app to analyze its performance over the period.

2.2 Use case: learning the English alphabet, words, and construction of short phrases/sentences

The details of the chosen use case are as follows:

1. A child picks one card at a time to learn letters from "A" to "Z" or "a" to "z".
2. Scanning a selected card using the camera will augment a 3D uppercase as well as a lowercase letter in real. A child will also get an option to listen to the sound of the letter chosen.
3. A child will learn how to construct three-letter CVC words. To construct a three-letter CVC word, a card corresponding to the letter will be scanned and placed at the actual location that can constitute a word. Scanning each card in front of the Mobile camera will augment the letter in uppercase and lowercase and read aloud the sound. Once all three cards are scanned and placed at their location, if they constitute a word found in the dictionary, an augmented representation of the object will be shown to the child, and word will be read aloud.
4. A child will learn how to construct four-letter words following the procedure, as mentioned above.
5. To demonstrate the learning of words, a child will learn how to construct phrases/short sentences of four words. While learning the construction of these phrases/short sentences, one or two out words would be randomly placed by the teacher/caregiver. The placement of words would be a guide for the child to think and select the remaining words and place them in the correct sequence. This way, all the words can be scanned from the dictionary to verify if a correct phrase/sentence is constructed. The number of words initially placed by the teacher/caregiver will be based on the need and level of an individual and will slowly fade away based on their progress. For instance, if the phrase/sentence is "A fish can swim," and the word "fish" is scanned and placed on the second position by the teacher/caregiver. The child will see the content augmented as they progress. In the current example, a child will see a fish. Once a child has placed all four words correctly, a child will see an animation of fish swimming in the water. If a child puts an incorrect word, then it will be guided by showing a cross sign at the location where a word is placed and a sound to give them a hint that they need to place another word instead.

2.3 Functionalities

The learning of content incorporated in MARVoc includes:

1. Mixed-mode letters: 26 letter cards that show uppercase and lowercase letters
2. Three-letter and four-letter CVC words that can have a visual representation
    a. CVC words beginning with ‘A’ or ‘a’.
    b. CVC words beginning with ‘E’ or ‘e’.
    c. CVC words beginning with ‘I’ or ‘i’.
    d. CVC words beginning with ‘O’ or ‘o’.
    e. CVC words beginning with ‘U’ or ‘u’.

The MARVoc consists of two phases, namely the learning phase and the activity phase. Each phase is briefly described below:

1. Learning phase:
In this phase, a child can either select mixed-mode letters or three-letter CVC words to learn. The learning of individual letters and CVC words is explained below:
1.1. Mixed-mode letters:
A child chooses one card at a time to learn alphabets from ‘A’ or ‘a’ to ‘Z’ or ‘z’. Scanning a selected card in front of the camera will augment an alphabet in uppercase as well as lowercase in real. It also shows a 3D pictorial representation of a word starting with the selected alphabet and provides an option to listen to its pronunciation multiple times by clicking on the Speaker button. The child can also perform an interaction with the object using transformation operations like rotating the letter or picture to view either of them from a different angle or scaling their sizes.
1.2. CVC words with three-letter:
In this subphase, a child will learn how to construct three-letter words. A card corresponding to an alphabet will be scanned and placed at the actual location that can constitute a word. Scanning each card in front of the camera will augment a letter and its pronunciation will be played. Once all three cards are scanned and placed at their locations; if they constitute a word found in the dictionary, then a child sees an augmented representation of the object and hear the pronunciation of the word, letter-by-letter followed by the complete word. The pronunciation can be played multiple times by clicking on the speaker button.
Note: The child can interact with the visual representation of a letter, or a word like rotating or scaling are the same as explained above.

2. Activity phase:
In this phase, a child needs to choose one of the following eight activities:
A. Construct three-letter or four-letter words.
B. Construct three-letter or four-letter words starting with a given letter.
C. Construct three-letter or four-letter words ending with a given letter.
D. Construct three-letter or four-letter words that contain a given letter.

Each activity is a timed activity and allows a child to use their imagination to construct as many words as possible. When a child constructs any word, it will:
A. Appreciate if a constructed word is correct and provide an opportunity to interact with the visual representation as mentioned above.
B. Inform the child that word is incorrect and motivate them to construct another word

At the end of the activity:

A. A child will be shown all the words constructed; for each word, a child will also see if a constructed word was correct or incorrect.
B. If all words were correct, then a child will receive a badge as an appreciation. They can collect as many badges as possible.

3 MARVoc prototype

From the interviews, it was found that iPads are used in the classrooms for teaching and activities. Therefore, it was decided to develop the first version for the iPad only. The initial version of the prototype is developed for an iPad and supports English language only and learning of up to three-letter words. The screenshots of the initial version of MARVoc are shown from Fig. 1 to Fig. 6. The staff taking part in the usability evaluation was the same who gave interviews. For the evaluation, the staff was briefed about MARVoc, its functionalities, and was allowed to use MARVoc.

Fig. 1 shows two options for a child to choose from; the training part is the same as of the learning part, while the activity part is the same as described in subsection 2.3. If a child selects an option of training, then two options, as shown in Fig. 2, will be provided to the child. This allows a child to choose either to learn 26 letters from the English alphabet or construction of three-letter CVC words.

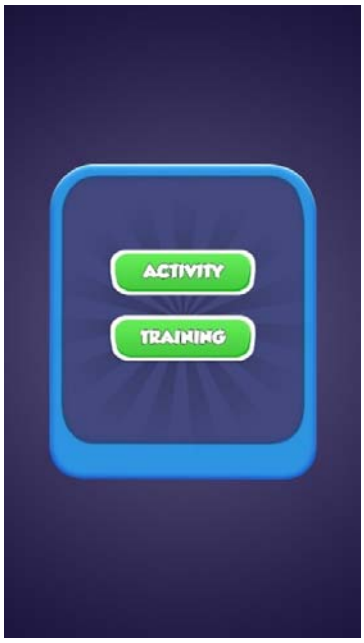

Fig. 1. The first screen to choose an activity or learning

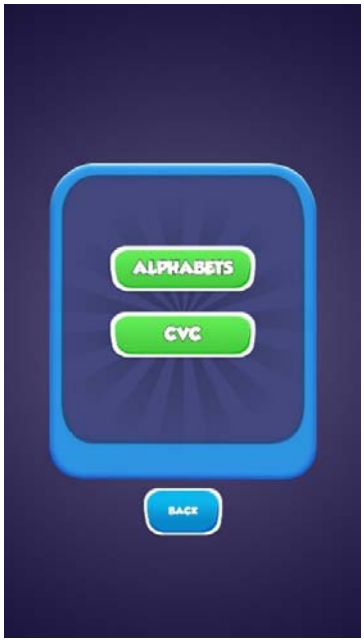

Fig. 2. Second screen to learn alphabets or CVC words

Fig. 3, Fig. 4, and Fig. 5 are related to the construction of three-letter CVC words. As mentioned in section 2.3, a child will be shown four options to choose from as a part of the activity; these options include the construction of CVC words in random order when a word starts with a specific letter when a word ends with a particular letter or a word which contains a particular letter. The format of learning to construct CVC words of constructing CVC words as a part of an activity is the same. If a child chooses the first option, then a child sees a similar screen, as shown in Fig. 5. However, if a child chooses any other option, then a child sees a screen like Fig. 4; this provides a child an opportunity to choose a letter that will be required in a CVC word to be constructed based on the option chosen, as shown in Fig. 5.

Fig. 3. Third screen to choose an option to learn or take part in an activity

Fig. 4. Fourth screen to select a letter to learn or for an activity

Fig. 5 allows a child to construct the CVC words; as per the instructions shown in the dialog box at the center of the screen, a child chose the first option from Fig. 3 and chose the letter "B" from Fig. 4. Once a child knows the instruction, clicking on the close button of the dialog box will make the box disappear from the screen. Based on the option selected, the location to place a letter "B" in the word is randomly chosen by an algorithm. The blue rounded rectangle with a star on the top-left corner and a letter inside indicates that it can be part of the word, while the red rounded rectangle indicates that a child needs to scan a letter for that specific position. The format of a marker for each letter is shown in Fig. 6. The marker shows an uppercase letter in the center, lowercase letter in the lower-right corner, and a pattern in the background. The background is different for each letter and helps in image detection and recognition when a marker is scanned.

Assume, a child scans a letter "Z" for the second position, since there is no three-letter word which starts with "BZ", a child will see a cross icon in the center of the screen to indicate that they have selected an incorrect letter. Now, assume if a child selected a letter "A"; since there can be a three-letter word which starts with "BA", the current red rounded rectangle will turn into a similar first blue rounded rectangle. Lastly, if a child selects a letter "T" or any other letter to form a three-letter word, present in the dictionary, then the last red rounded rectangle will turn into a blue rounded rectangle like the other rounded rectangles. Then, a child will see a 3D representation of the word and listen to the pronunciation of the word as well. As mentioned

earlier, a child can repeatedly listen to the pronunciation of the word and scale and rotate the object.

If at any point a child wants to clear the letters placed so far, then clicking on the "Reset" button will remove the letters placed and allow a child to construct a new word of their choice. If a child wants to select any other letter to be part of the word, then they can click on the "Back" button. Similarly, if a child wants to select any other option as shown in Fig. 3, then clicking on the "Back" button will take them back to Fig. 4, and clicking on the "Back" button again will take them to Fig. 3 to select one of the four options. It is to be noted that the algorithm will still choose the placement of the letter in the word.

Fig. 5. Fifth screen to construct a three-letter CVC word as a part of the learning or an activity

Fig. 6. An example of a marker used in the MARVoc

3.1 Prototype feedback

The staff at both centers use several mobile applications as a part of day-to-day teaching or intervention of children with ASD. Therefore, they were used as experts to provide feedback on MARVoc so that usability aspects can be improved before children with ASD start using it for the learning. The feedback provided by the staff are as follows:

- The font face is inconsistent in Fig. 5.
- The background is inconsistent in Fig. 5.
- Animation of rotating lines in the background may be distracting to some children with ASD. There should be an option like a checkbox of "Background animation" to let the user decide if s/he wants an animated background or static.
- Connectivity of the back button on screens is incorrect.
- All the actions performed by the user on the screen needs to be recorded, not just on a specific part like "Training" or "Activity".
- Feedback should be visual (picture and text) and audio.
- Vowel letters (A, E, I, O, U) are missing in the "Select Letters" screen on Fig. 4
- Place "How do you want to create words?" on top of 4 options "Random", "Start with" etc. in Fig. 3.
- The instructions provided in Fig. 5 should be viewable.
- In Fig. 5: When a user clicks on the close button of the dialog box, the instruction/question disappears. It should be placed on the top, followed by the 3 letters.
- Increase the size of curved rounded rectangles with a letter in Fig. 5.

- A child may not know what does “B” in a curved rounded rectangle in Fig. 5 indicates? They need to start scanning the markers from the “B” so that all three markers are placed next to each other to form a word; otherwise, they may only scan “AT”.
- There should be an arrow blink below the first rectangle to indicate waiting for the marker of the first letter to be scanned. This would only be possible when the instruction/question remains on top.

4 Conclusion

This research presents a Mobile augmented reality app for the vocabulary learning of children with ASD (MARVoc). The requirements for the MARVoc were gathered using semi-structured interviews from the teaching staff working at two centers based in Doha, Qatar. These requirements were gathered to ensure that the needs of local children with ASD have been incorporated in MARVoc. Based on the requirements, two detailed use cases were developed and discussed with the focal persons at both centers, and one of the two use cases was finalized for the prototype. The staff working at both centers were given a demonstration of the initial version of the prototype to determine its effectiveness in learning vocabulary for children with ASD. The feedback was taken from the staff, and MARVoc was updated. MARVoc is being deployed at Step by Step Center for Special Needs for use by the staff in the classrooms. MARVoc is also being modified to incorporate four-letter CVC words and construction of short phrases/sentences. The new version of the MARVoc would also include Arabic letters and words so that it can be evaluated with the children with ASD at Shafallah Center for Children with Special Needs. The new version of the MARVoc would support the user to change the user interface from English to Arabic and vice versa.

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