Developing Computational Thinking for Children with Autism using a Serious Game

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Abstract—Autism Spectrum Disorder (ASD) refers to a group of life-long conditions that are characterized by qualitative impairments in social interactions, problem solving and constructive skills. Children with learning disabilities such as autism face challenges in generating suitable and optimal solutions to problems. These challenges can severely affect their interactions with others. Thus, teaching children with ASD problem solving and computational thinking skills could help them resolve conflicts that may happen in their everyday life. Effective problem solving is critical for their academic and social success and since one of the most effective tools for teaching children with autism is through using visual aids, the work in this paper reports the design and implementation of a serious game that aims at cultivating problem solving skills and teaching programming concepts to children with ASD. The presented game is suitable for children 7 to 14 years of age diagnosed with ASD to learn programming concepts. The preliminary prototype for the game gained positive responses from experts and 12 children with ASD from Caritas Egypt association and Hope Academy.

Index Terms—Computational Thinking, Visual Learners, Children, Autism, Programming

I. INTRODUCTION

Autism spectrum disorder (ASD), also known as autism, is a general term that refers to a complex lifelong neuro developmental range of conditions. ASD is mainly characterised by qualitative impairments in social interactions, social imagination, speech and nonverbal communication, language functioning, problem solving and constructive skills [1]. Global statistics shows that autism prevalence increases every year in a rate between 10% and 17% [2]. Although there has been found no cure, early diagnosis and intervention can improve a child’s overall development and leads to positive outcomes in the education and social life of children with autism [3].

The term Computational thinking was defined by Seymour Papert in 1980 [4] as a set of problem solving processes. Computational thinking requires recognizing the problem, generating multiple solutions, then selecting the optimal solution, and last but not least evaluating the effectiveness of the selected solution. It is an essential method to approach complex problems in a systematic and effective way [5]. Additionally, it is a crucial skill for this century in the workplace as well as in educational settings [6]. Often students with autism spectrum disorder face challenges in problem solving, which can severely affect their interactions with others [7].

Computer-based interventions for children with ASD have proven to be useful and effective [8] [9] due to several reasons:
1) Most technologies use visual interfaces, which goes along with the characteristics and preferences of individuals with ASD [10] [11]. 2) Considering that social interactions might be overwhelming for children with ASD [12], they are more drawn to computing which is free from social demands [13]. 3) One of the key benefits of software development is that it provides a controlled environment with immediate feedback and no surprises, which is suitable for children with ASD. 4) One of the reasons why they might be attracted more to computer programming specifically, is that it is consistent and logical [13].

In addition to being effective for therapeutic purposes, computer-based approaches for educational purposes for children with ASD have got attention in the previous several years, since they have proven to be effective in teaching concepts and skills as well. Tsikinas showed that the majority of studies performed on the effects of serious games for people with ASD had a positive impact [14]. This is promising for teaching children with ASD computational thinking through a serious game intervention.

The use of serious games is accepted by people with developmental disabilities in general, because of several reasons. First, they feel comfortable exploring the virtual world which does not include the pressure existing in the real world. Second, since computers are considered as an important tool nowadays, people with developmental disabilities feel proud to be using it [15]. The proposed interactive serious game in this paper targets teaching the three different programming concepts; sequential, conditional and iterations, to children with autism.

One of the most effective tools for teaching children with autism is using visual aids [16] [17]. Children with ASD often find it difficult to understand and follow spoken instructions. Visuals can promote appropriate, positive ways to communicate. Research has shown that when children with ASD are given the chance to learn with visual cues, this helps them: 1) learn quickly 2) gain independence 3) decrease anxiety. Thus, an interface with more visuals (pictures, drawings, animations along with written cues) can help them communicate and tend to be engaged more [18] [17]. A serious game can use engaging multimedia formats in order to be an effective tool for educational purposes. Using multimedia can make the game creative and visually attractive. Hence, fitting the learning styles and characteristics for children with ASD [16].

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This paper is organized as follows. Section II reviews the published work related to the topic presented in this paper. Section III introduces the ADDIE model used in this study along with presented game’s features. Section IV includes details about the game structure. Finally, Sections V and VI present our conclusions and suggested future work.

II. Previous Work

A. Computer-based interventions for teaching concepts and improving skills

Several applications have targeted the development of skills and teaching concepts through computer based approaches. As contended in [19], Arshia et al. (2011) proposed an interactive serious game based on the story-telling concept and appealing graphics which helps in teaching children with autism the concept of money. Additionally, the game teaches children the social behaviour appropriate while shopping. The game received positive response from participants and was effective in teaching the children the concept of money.

I-interact is another virtual reality serious game that helps improving eye gaze abilities for children with autism and aims to transfer those acquired skills to real-world social interactions [20]. Developers made sure to use 3D human avatars to help users identify themselves in the game, and realize the connection to real-world situations. According to the evaluation carried out, the game was proven to be effective for eye contact improvement of children with social deficiencies including autism.

B. Computer-based interventions for cultivating computational thinking

A number of applications and frameworks were developed to cultivate computational thinking for children through attractive visual interfaces. Scratch, for example, is a block based programming tool developed by a research group in the MIT Media Lab. The tool allows the users to create interactive stories and animations with blocks of code by a drag-and-drop mechanism.

Code.org is a platform that aims to expand participation in computer science by encouraging people to learn computer science. The goal of Code.org is to demystify the meaning of code and prove that anyone can know the basics of programming, including children [21]. The findings of the study in [21], show that after the participants tried the tutorials on Code.org, they became much more interested in programming. However, Code.org’s interface might have complicated and overwhelming graphical user interface for children with autism, who need to have simple interfaces in the applications they use as depicted in [22].

C. Visual teaching strategies for children with ASD

Many research studies have investigated the different learning methods suitable for children with autism and similar developmental disorders. Learning through using visual cues has proven to be the most effective method of teaching [23]. Researchers in [24] reported the design of a computer serious game that uses 3D human avatars to reinforce problem solving and emotion recognition for both normally developing children and children with ASD. The game had mainly two parts, a playable introduction and a coding interface resembling Scratch which focuses on teaching children with ASD programming logic. However, the application was in development stage and the study has not shown the effectiveness of using the game with children.

III. System overview

The aim for the implementation of the presented game is to teach children with autism Computer Programming basic concepts, namely; sequential, conditional, and iterations programming concepts. The game consists of three modes (Entry, Intermediate and Advanced), each mode constitutes three levels. The five-phase ADDIE model (Analysis, Design, Development, Implementation and Evaluation) [25] [26] was used as the research design to develop the presented framework.

A. Analysis

Our framework targets children with ASD. Thus, it was crucial to determine the characteristics and learning styles of the targeted group. The requirements for an interface designed for children with ASD were the outcome of multiple meetings with experts from "Caritas Egypt". "Caritas Egypt" is a local centre whose mission is to provide adequate services to people with disabilities and focuses on developmental disabilities, including ASD. Accordingly, the game environment and methodology were identified in the analysis phase.

B. Design

The design phase included a meeting of two sessions with experts from Caritas. The first session involved brainstorming about the meaning of computational thinking. This session included clarifying the idea behind the presented framework, and experts giving feedback from their side. The most essential points advised for our framework can be discussed as follows: 1) The interface visuals should be simple, as not to overwhelm children [22]. 2) To help children identify themselves in the game, a 3D human avatar that matches the child’s gender should be used. 3) Every correct action should have immediate visual and auditory feedback, and the selected feedback should be consistently used as a rewarding mechanism throughout the game [15].

Several design elements were proven to motivate the user to play the game [27]. These elements include the following: immersive storylines, rewards and feedback about goal progress, increasing levels of difficulty and provision of choice. The storyline used throughout the game is related to everyday tasks that a child can accomplish around a house. Storyline can help in enhancing motivation to play the game. The game also allows the user to choose between different difficulty levels, as advancing levels of difficulty increases engagement, motivation, and learning.
C. Development

Gathered information from research along with the advised points from the Caritas team were taken into consideration throughout the development phase of our framework. The framework features and elements can be discussed as follows:

1) Game Scenery: As contended in [28], children with autism can learn better if the tasks given within an application is linked to tasks that the child is already familiar with. Thus, a home was chosen to be the scenery of the game. Additionally, to make the game personalized for each child, the home 3D objects can be rearranged from the main menu of the game. The game environment can be shown in Figure 1.

2) User interface & Player: A 3D human avatar that matches the child gender was used to be the guide character throughout the game. The first-person perspective displays the 3D avatar can be controlled with a keyboard.

3) Visual Supports: The game includes 1) “To-do” list: consists of several tasks that the player has to complete in the correct order. Another level has a daily schedule that the player can check to accomplish tasks. 2) Guiding text: placed in the lower corner of the screen to guide the player throughout the game, gives a proper feedback and mentions the next task to be done.

4) Feedback & Rewarding mechanism: The feedback system in our framework is delivered both visually and acoustically. In particular, a check mark image is displayed besides each task once being accomplished successfully. At the end of each level clapping sounds play as a reward.

D. Implementation

The second session with Caritas took place after the development of a preliminary prototype of the game. The prototype was developed using Unity 3D game engine and had only the first two levels of the game. The comments from this phase can be discussed as follows: 1) add more visuals to the game (Adding a check mark besides each task after being successfully accomplished). This was added later to the game. 2) to add levels that relate to problems parents face with children. Thus, a level related to the preparation of the school bag was added to help the children link the skills to their real-life situations.

E. Evaluation

A prototype of the game that only had 2 levels for the sequential programming concepts was evaluated. Evaluation was made through two focus groups. The first group consisted of 8 normally developed children. The first group evaluation was beneficial to make sure that the graphics and the layout are appealing to children in general before trying it with children with ASD. The results for this group showed that the game is suitable for the use of children and game graphics and models are appealing to children. The second focus group of 4 participants with autism. The results of the evaluation of the second group showed that the game is engaging for children with autism. A detailed description of the study evaluated can be shown in [29].

An additional evaluation phase had been carried out with a local intervention center "Hope Academy for Special Needs" in Egypt. Another focus group of four boys and four girls diagnosed with ASD was formed. A detailed presentation of the participants can be shown in Table I. Participants were of ages ranging from 7 to 14 years old with an average of 11

\footnote{National Educational Association of Disabled Students}
years. All of the participants were diagnosed with ASD except for one participant who has a developmental delay. Participants are of varying age groups, since almost always autism is associated with learning disabilities. The engagement test was a one session test of 20-30 minutes for each participant. The participants were accompanied by their instructors throughout the session. A survey that evaluates the overall engagement of the user through nine points with five Likert scale responses, derived from [30] was filled by the instructor after the child play the game.

TABLE I: Participants for the engagement study

<table>
<thead>
<tr>
<th>ID</th>
<th>Gender</th>
<th>Age</th>
<th>Condition</th>
<th>Computer skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>Male</td>
<td>10</td>
<td>Autism</td>
<td>Basic</td>
</tr>
<tr>
<td>P2</td>
<td>Female</td>
<td>9</td>
<td>Developmental delay</td>
<td>Moderate</td>
</tr>
<tr>
<td>P3</td>
<td>Female</td>
<td>14</td>
<td>Autism</td>
<td>High</td>
</tr>
<tr>
<td>P4</td>
<td>Female</td>
<td>11</td>
<td>Autism</td>
<td>Basic</td>
</tr>
<tr>
<td>P5</td>
<td>Male</td>
<td>13</td>
<td>Autism</td>
<td>Moderate</td>
</tr>
<tr>
<td>P6</td>
<td>Male</td>
<td>12</td>
<td>Autism</td>
<td>Moderate</td>
</tr>
<tr>
<td>P7</td>
<td>Female</td>
<td>12</td>
<td>Autism</td>
<td>High</td>
</tr>
<tr>
<td>P8</td>
<td>Male</td>
<td>7</td>
<td>Autism</td>
<td>Basic</td>
</tr>
</tbody>
</table>

A detailed description of the data collected from the engagement test conducted can be shown in Fig.2. Each bar shows the average results of the participants for each question in the survey. As shown, the study yielded positive results. Almost all of the participants were in full control of the game and knew what to do exactly. All of the participants found the game enjoyable and interesting. This suggests that with the proper exposure time to the game, it might be an effective tool for teaching children with ASD programming concepts and problem solving skills.

A kitchen was chosen as the environment for the first and easier levels. It is recommended for novice programmers to begin with this level. The aim of all levels in this mode is to prepare a lunchbox for the following school day.

1) Sequential Level: The first level addresses sequential programming concepts. The player should follow several sub tasks in a certain order to complete a task. Those tasks are shown on the storyboard of the game. The player has to collect fruits in the correct order and drag each item to its corresponding target on the table. The fruits can be collected by a drag and drop mechanism. Appealing 3D objects were chosen to be the targets. The level can be shown in Figure 3.

Fig. 3: Sequential, Entry mode

2) Conditional Level: As shown in Figure 4, the player is given all the fruits, and a schedule is to be shown on the top of the screen. The player has to drag the items that are on the schedule. If today is Sunday, for example, the schedule for Sunday will be shown and the child has to collect only the correct items for that day.

Fig. 4: Conditional, Entry mode

3) Iteration Level: In this level, the rest of the items that were not collected have to be put back to the kitchen table. The items have to be returned one by one until the plate is empty. This level can be shown in Figure 1c.

IV. GAME STRUCTURE

The game aims at teaching children with autism the preliminary steps of logical thinking and programming concepts, namely; Sequential, Conditional and Iteration concepts. Thus, the game provides three static difficulty modes: Entry, Intermediate and Advanced. Each mode has three levels that target the three concepts. Variant difficulty levels will offer the players some sort of control over challenges and provide them the opportunity to experience the virtual environment in different difficulty settings.
B. Intermediate Mode

A bedroom was chosen as the environment for the second difficulty level. The aim of all levels in this mode is to prepare the bag for the following school day. The 3D objects for this mode are more complex, where the player has to read the books’ titles to be able to collect them in the correct order.

1) Sequential Level: This level requires the child to collect all the books of all the subjects to the bag. First the child is asked to go to the book shelf in the right corner of the room. After that the child has to collect the books shown in figure 5 in the correct order.

![Fig. 5: Sequential, Intermediate mode](image)

2) Conditional Level: The same schedule idea is repeated again but in a more difficult way. The items are a little bit more complex where the child has to read the book titles to be able to solve this level. A screenshot of the level can be shown in Figure 6.

![Fig. 6: Conditional, Intermediate mode](image)

3) Iteration Level: The last level for this mode addresses the iteration programming concept. The player has to place back the unused books from the previous level. As shown in Figure 7, the player has to drag each item to its placeholder until the shelf is empty.

![Fig. 7: Iteration, Intermediate mode](image)

C. Advanced Mode

A living room was chosen to be the scenery of the hardest mode for the game. Throughout this mode the player has to decorate a Christmas tree. The challenging task in this mode is to determine the difference between the various mathematical shapes of the 3D objects representing the gifts (rectangular, circular and square) in the game.

1) Sequential Level: This level requires collecting Christmas gifts and tree decorations from the living room table. The items to be collected are shown in figure 8. Items have to be collected in the given order shown by the storyboard of the game.

![Fig. 8: Sequential, Advanced mode](image)

2) Conditional Level: This level can be shown in Figure 1b. The player has to place the correct items shown on the schedule. A given schedule of (Friday and Saturday) is displayed on the screen, the only two days the child is allowed to decorate the tree, the player is required to check what tomorrow is and choose the items according to the schedule.

3) Iteration Level: The last level requires the player again to return all the unused decoration items back to the living room table. In addition to the clapping sounds, an extra reward is given after finalizing all of the tasks. The reward is a 1 minute clip from the player’s favourite cartoon movie.
V. Future Works

We plan to offer more customization options in the game to make it suitable for each child’s special and unique traits. We plan to extend the game to teach children more complex concepts such as data types. Also, we plan to experiment with more children with autism and for long periods of time in the future to be able to check the effectiveness of the game in cultivating computational thinking and programming concepts in children with developmental disabilities including autism.

VI. Conclusion

Although autism has no cure, early interventions for educational purposes have proven to be effective. Computer based interventions have proven to be very powerful in cultivating concepts and teaching skills. Serious games help children with autism experience a controlled virtual environment free from social demands. When children with autism are visually engaged, they tend to be immersed more which improves their learning skills. Thus, serious games are suitable for the learning styles of children with autism. We presented a serious game that aims at cultivating computational thinking skills and basic programming concepts for children with autism. Positive responses have been obtained from experimenting the preliminary prototype of the presented game.

References