Galaxy Shop: Projection-Based Numeracy Game for Teenagers with Down Syndrome

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Abstract. Teenagers with Down syndrome face difficulties in acquiring new skills specially in the tasks that need high cognitive abilities. In the recent years, serious games showed to be a promising assistive mean in the field of education. Augmented Reality (AR) technology is a growing research area that could be achieved by different ways for many purposes. The main focus of this study is investigating the effect of using a projection based game for Down syndrome teenagers in an educational context. This was done through implementing a game that aims at enhancing their numeracy skills for financially independent living. The developed interactive surface game was tested with a number of Down syndrome teenagers, and its effect on their learning outcomes was compared to the effect of the same game played on the normal technological mean they receive, namely the personal computers.

Keywords: Down syndrome · Serious games · Augmented Reality · Education · Numeracy

1 Introduction

Down syndrome teenagers exist across a huge part of our societies. According to DSA[1], Down syndrome continues to be the most common chromosomal disorder with a rate of 1 in every 700 babies born each year. Accordingly, the problem of promoting learning for students with Down syndrome has attracted much of the theoretical and practical research because of its importance and effect on the society development. Teenagers with Down syndrome differ in their educational achievements and cognitive skills. Research reveals that they follow the same educational progress as their developing peers who do not suffer from Down syndrome [4], only more steps and practice are needed in each stage to reach the planned educational objectives. Some studies show that exploiting the visual learning strengths of students with Down syndrome using the available technologies can promote their learning process [6].

One of the promising approaches to promote learning is the usage of games as an assistive teaching mean [5]. Some studies have identified serious games as a good way of education, as they help in increasing the motivation of the students to enjoy the

[1] The Downs Syndrome Association, United Kingdom.

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learning process [8]. Moreover, they can offer some factors that the regular teaching methods lack [2]. The usage of projection-based augmented reality (projected AR) to build interactive educational systems for different profiles of students is a well established research area [12, 23]. It is a growing field of technology which allows computer generated virtual imagery to exactly over-lay physical objects in real time so that the user's real world become digitally manipulable and interactive. Research has indicated that projected AR systems and environments could help learners develop skills in an effective way [24]. The combination of projection based technology and educational games might have the potential to create new type of applications that enhance the attractiveness of the learning process, and transform the classroom into an exciting environment specially for cognitively challenged learners, where they can become active participants [23].

In this study, the existing strategies built for teaching Down syndrome teenagers has been investigated, taking into consideration the input of the experts in the field, to build an engaging projection based AR system. This was done through implementing an educational game aiming at enhancing the numeracy skills of Down syndrome teenagers for independent living. [6] defined numeracy as "using mathematics effectively to meet the general demands of life at home, in paid work, and for participation in community and civic life". The game is called Galaxy Shop, it aims at teaching them the advanced numeracy skills needed in their daily life like addition, subtraction and multiplication, which enhances their independence in the different aspects like budgeting their money, splitting a bill, and shopping. The game was implemented using projection based technology, namely interactive walls, where the learner is able to learn through interacting with a projected image on the wall of the room instead of using the traditional teaching instructional means.

An experiment was conducted to evaluate the effect of the developed game on the learning process of the students. Two variants of Galaxy Shop were tested with a number of Down syndrome teenagers. The first one presented the projection based version of the game, and the second one represented the normal version of the game, where the conventional computer based mean was used. The tests were held to compare the effect of using projection based games on two aspects: the learning achievement of the participants, and their level of engagement during the learning process.

2 Projected-AR Game Based Learning Effects

In the recent years, many research studies have been conducted to explore the effectiveness of using serious games for learning [5, 9]. [10] elaborated that games help motivate students to continue the learning process for a longer period of time. Most of the studies has reasoned the potential of using educational games to the presence of the factors that the normal learning methods lack like having a system of objectives, goals, rewards, and rules of play [1, 8]. According to [1], interactivity is a critical element in effective educational games. Highly interactive games are considered to be the most effective ones as they give the learner the sense of freedom and enjoyment that creates a better learning experience without being bored or unchallenged.

Experiments for interactive learning provided by projected AR is increasingly recognized by researchers. According to [12, 24], it creates enhanced reality by bridging virtual and real worlds, it can be considered to be one of the tools providing students with an engaging technology mediated learning experience. AR could be used for cognitively challenged students as well. [13] reports that projected applications can improve students' spatial abilities, as they could receive real time feedback that may enhance their performance in cognitive tasks. The reason behind that is the existence of multisensory cues in projection based systems that offer the ease of use, engage the students, help them digest the educational material, and prevent errors through instant feedback [1].

Although there exist studies that show evidence about the positive effects of using projected AR in learning, some studies report negative effects and challenges for using this technology in the field of education. [12] reports that students could be cognitively overloaded by the large amount of information they get exposed to, and the complicated tasks they are required to accomplish. More-over, they can be confused and overwhelmed in an AR environment because of facing a situation of mixed reality. They might lose track of the real environment which is not suitable for some learners and may result in negative effects specially if they lack some skills like problem solving, mathematical estimation and collaboration [17]. Due to the previously mentioned challenges of using AR environments, Down syndrome students might be frustrated using such technology.

To Sum up, while projected AR technology offers new learning opportunities in the filed of education, it also creates various challenges for educators. Hence, further research and experimentation need to be held in order to evaluate the effect of embedding AR in education.

3 Related Work

Many research studies have investigated the potential of using projected AR technology and serious games for learning. The evidence provided about the impact of such games is mixed [2, 12, 17]. An overview of the existing work in this field is presented in order to highlight the points of strength, extract the research gaps and incorporate such aspects in the proposed design.

[19] is a study that was held to determine if computer assisted means of teaching facilitates the learning process of basic mathematical abilities in children with Down syndrome, as compared with the paper based teaching method. One group was taught using computers, while another group took the same training printed on a paper. The results of the study showed that computer assisted teaching is more effective than the traditional paper based method as it increased the mathematical abilities of the participants. [18] is a study that tackled the effect of using AR based educational games on children. The study introduced an educational game called TNT Adventure that is played using Kinect. It encourages students to collaborate in remote environments through making choices that determine the actions of two characters in their daily life. Each player is represented by a hand and an icon in the game. After testing the game in

three kindergartens, it was found that children are more motivated and collaborating healthily with each other upon interacting with the game.

[20] is an online serious game that helps students acquire general knowledge about electrical engineering. The participants were divided into two groups: the first one learned the content by playing the game and the other by actual text. The results showed that the males who played the game were better able to answer questions on the theory than the males who studied the text. For the females, there was no difference between both groups. Moreover, [21] introduced a math facts game that was deployed on handheld computers for second graders. They found that learners playing the game completed nearly three times the number of problems in as those using paper worksheets. [22] is a research study that investigated the impact of two teaching scenarios of an art course on 69 middle-school students in Madrid: the first one is based on slides and the second one is based on AR technology. The quantitative results of this study showed that AR technology usage had a positive effect on the motivation of the students and diminished the barriers found to apply AR massively on schools.

To sum up, the existing work shows the potential of using AR game based systems for learners. Such work included useful features that were harnessed in our design. Some gaps exist and need to be filled, among which: addressing Down syndrome learners through providing them with the needed teaching strategies, and adding the interactivity factor in the educational means. Moreover, most of the studies either tested the effect of using projected AR technology or the effect of serious games. There is a rarity in the studies that compare projection based methods with computer based methods. This raises a need for having a game that utilizes all aspects together, and embeds both methods in the same experiment.

4 Methodology

Students with Down syndrome face learning difficulties due to having have special developmental pro les. Research suggests that they learn better when they can see things illustrated [19]. This finding has been demonstrated across a number of areas, as teaching can be more effective when information is presented with the support of pictures, gestures or objects. Most students with Down syndrome struggle with basic number skills and their number skills are two years behind their reading skills [6]. Galaxy Shop is a projection based educational game that exploits their learning strengths through making use of visual supports that the technology offers. It helps them to be financially independent through introducing advanced numeracy skills in an engaging way. The game is implemented using projection based technology, where the learner is able to solve the different mathematical problems by interacting with a projected image on the wall of the classroom instead of using the normal hardware tools of computers like mouse and keyboard as clarified in Sect. 4.3.

4.1 Material and Structure

Galaxy Shop was implemented in a way to make it easy for the students with Down syndrome to absorb the educational content in the game. It is divided into three levels:

beginner, intermediate, and advanced. The beginner level represents simple addition and subtraction operations, the intermediate level represents more advanced addition and subtraction operations and the advanced level represents simple multiplication operations. Each level consists of two parts, the first part consists of a sequence of multiple choice mathematical problems represented visually to the player, where he is supposed to pick the correct answer out of three choices. This part of each level consists of a problem set consisting of five consecutive problems on the same concept (addition, subtraction or multiplication). The problem is presented on the screen in a form of five balloons in the galaxy sky: two balloons for the quotients and three for choices, one of them contains the right answer as seen in Fig. 1.

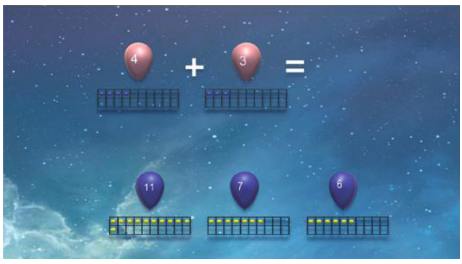

Fig. 1. Galaxy shop beginner level: cardinality based addition

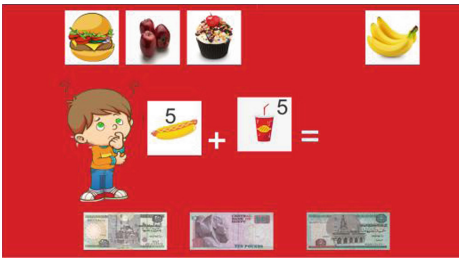

Fig. 2. Galaxy shop: real life application

The second part of each level is a real life application where the student is put in a situation in which he wants to eat or buy something and pays the price of what he chooses. The choices of money for paying is made with real Egyptian currency so the learner can relate to the situations he is exposed to on daily bases in any shop. The educators and experts in the field stated that the real-life application in each level is important for the needs of Down syndrome learners. According to [7] this is called "transfer in learning", which refers to the ability to apply knowledge in a different situation. Real life applications included in Galaxy Shop include buying food, beverages, shoes and candy from different shops in each level as shown in Fig. 2.

4.2 Game Design

Regarding the game design, it was tailored to meet both the educational and psychological needs of Down syndrome teenagers. Most of the fundamentals of game design were made based on the existing learning theories presented by [6] for DS students, in addition to the recommendations of the experts for this target group. Regarding the educational aspects, the first quotient is always larger than the second quotient, so that when having two numbers to add, the learner puts the bigger number in his head which is the first quotient and then adds up the second quotient to reach the answer. Moreover, there is a help panel at the home page of the game assisting the learner in the three levels. Also, the game is designed based on the cardinality system [6]. Hence, a rectangle containing balls representing the number exists below each quotient to help

students use the cardinality method while solving the problem as shown in Fig. 1. Additionally, there are key mechanics for successful computer games for cognitively challenged children like: multiple exemplars, variety in methods used to teach concepts, on-repetitive trials, and customization [2, 8], these components were successfully embedded in Galaxy Shop.

Regarding the psychological aspects, motivation is one of the main features embedded in the game as it is considered to be one of the important keys of learning because it helps the student to be fully engaged in learning process [8]. According to [7], repetition plays a vital role in any learning strategy. Hence, Galaxy Shop was designed so that when the student answers correctly, the selected balloon color will change to green, reworks will appear and a panel containing the score is displayed in order to give the student confidence and motivate him to solve the next generated problem. On the other hand, when the student answers wrongly, the balloon changes its color and turns back to its place so that he tries till he gets the correct answer. To sum up, the main pillars of this game design are: using clear material, giving extra praise means, using hints, and avoiding score deduction upon wrong answers.

4.3 Implementation

Projection based technology is one of the most emerging technologies that can be used to create unique learning experiences through converting any surface into an interactive one [1]. Galaxy Shop is a projection based game that was built upon many stages. First, implementing the game based on the background of the target group, then integrating it with the projection based technology used, which is interactive wall, and finally testing if it is more effective than computer based means. The game was implemented by Unity game engine [14] and the interactive display was achieved using Touchizer [16]. It is a device attached to a projector that can change any surface into an interactive and collaborative work-space like walls, tables or any ordinary whiteboard up to 100 inch [16]. An infrared pen is used to tap on the interactive surface and interact with it. We decided to use Touchizer rather than other options of interactive surfaces implementations as the results for its calibration are very accurate. Moreover, it is suitable, portable, reliable and easy to use in the classroom for the teachers or at home for the parents. Integrating the projection based technology with the implemented game is simple and can be applied on any other game. The first step is connecting the Touchizer device to the computer, that is connected to the projector. Then, the calibration process is done using a software program, and the students are ready to play with it easily.

5 Experimental Design

This work experiments the effect of using an AR projection based educational game for Down syndrome teenagers on their learning process, compared to using the same game on normal computers. This was achieved through implementing Galaxy Shop, and testing it with a target group sample. The null hypothesis states that there is no difference in the effect of using Galaxy Shop on Down syndrome learners when they receive it on two different means: interactive wall; and normal computers. The first

hypothesis (H1) claims that there is no difference in the learning gain level of the participants playing the AR projection based version of the game compared to the computer based version of it. The second hypothesis (H2) claims that there is no difference in the engagement level of the participants playing the AR projection based version of the game compared to the computer based version of it.

The model used is a between-group design one that has two independent sub-groups: control and treatment with equal number of participants. The treatment group used the 100 inch interactive wall version of Galaxy Shop, while the control group used the normal version on personal computers. Target participants were Down syndrome students who were chosen from centers and schools for special needs. The selection was based on the academic level reached in the curriculum, as they were required to have minimal mathematical skills like counting from 1 to 50. Their age ranged from 12 to 18 years old. However, age did not matter as much as the academic level of the learner, because different levels of severeness can be found across Down syndrome teenagers. The materials used in the experiment were questionnaires, hard copied tests for the participants, and consent forms for the parents. The experiments were held individually for each participant in normal classrooms. Teachers of the participants were asked to attend and required to fill the questionnaires needed in the evaluation phase.

6 Test Conduction and Results

This work is intended to be an extension for the study [15] that has tested the effect of serious games on children with learning disabilities. The objective is to construct various studies about using different assistive learning means for the educationally challenged groups. Hence, the same testing strategy was inherited and applied in this study in order to investigate the effects of different technologies on such groups.

A sample population of 18 officially diagnosed Down syndrome teenagers were randomly assigned into two groups (control group: n = 9, and experimental group: n = 9). Participants of both groups played the 3 levels of the game consecutively. In order to perform the comparison of the learning process between the two groups, learning gain as well as the engagement level of both groups were measured after using the corresponding learning mean. Analyzing the data comparison between the two groups was done using an independent t-test on SPSS (Statistical Package for the Social Sciences). The purpose of the independent sample t-test is to determine if there exists a significant difference in the learning gain as well as the engagement level between the independent groups included in the experiment.

6.1 Learning Gain Test

Procedure: Before using their respective version of educational technology, each participant had a paper based MCQ pretest in the material embedded in Galaxy Shop, the test consisted of three parts each representing a level in the game, the first part was about simple addition/subtraction, the second was about advanced addition/subtraction and the third was about multiplication; five questions each. An identical copy of the

same test was given after using the perspective technology. Participants were asked to answer the test with no help from the teacher. To ensure the homogeneity level of the experiment, the structure of the test was compatible with the material embedded in the game. Learning gain was calculated by subtracting the number of correct answers that the participant got in the pretest from the number of correct answers received in the post-test. By comparing the learning gain of both groups, conclusions were drawn about the educational effectiveness of the interactive wall version of the game versus the normal computer based one.

Results: The results of the test between the two groups revealed that after the two interventions, the learning gain resulting from using the AR version of the game ($M = 3.6$, $SD = 0.6$) was significantly higher than the gain of the other group which played the computer based version of the game ($M = 2.0$, $SD = 0.2$) ($t(9) = 2.3$, $p < 0.05$) with a difference of 1.65 and standard error difference of 0.68. This rejects the hypothesis stating that there is no difference in the learning gain level of Down syndrome teenagers playing the AR projection based version of Galaxy Shop compared to the computer based version of the same game (H1).

6.2 Engagement Test

Procedure: An engagement test was held for the participants in both groups. It is a 5-likert scale standardized questionnaire inherited from [11] that was also used in the study held for children with learning disabilities mentioned before [15], it consists of 9 items that measure the overall ow of any activity through measuring two factors: control, and enjoyment. A hard copy of the questionnaire was handed to the teachers after the session. They were asked to fill it according to their observations of the teenagers while interacting with the respective learning means. By comparing the results of both groups, conclusions were drawn about the engagement level of the learners experiencing the interactive wall versus those who used the normal computer mode.

Results: The results of the independent t-test between the two groups revealed that the engagement level of the group of learners who used the AR version of the game ($M = 4.54$, $SD = 0.32$) was significantly higher than the engagement level of the other group that used the computer based version of the game ($M = 4.01$, $SD = 2.48$) ($t(9) = 2.2$, $p < 0.05$) with a difference of 0.53. This rejects the hypothesis stating that there is no difference in the engagement level of Down syndrome teenagers playing the AR projection based version of Galaxy Shop compared to the computer based version of the same game (H2).

6.3 Flow Test

Procedure: Similar to [15], a flow test was conducted in order to examine the acceptance of the participants to each level in Galaxy Shop. Flow can be represented as a channel between the skill and the challenge the user finds in any activity [3]. Users will be anxious if the challenge is higher than the skill, and will suffer from boredom in the opposite case. Hence, to have a good ow in any activity, a balance between skill and challenge is needed. Ratings of the skill and the challenge levels of each learner were

taken after each level in the game. The questionnaire consists of two five likert scale questions: “How did the participant find this level challenging?” and “Is the skill of the participant appropriate for this level?”.

Results: For the flow test, Fig. 3 shows the skill versus challenge rates for Galaxy Shop, while Fig. 4 shows how far each level was from the desired ow level. According to [11], the distance is calculated by subtracting challenge from skill and multiplying the result by 0.25. The results show that during the first level the average of skill was higher that the challenge which means that this level was easier than expected for the participants. In the second level, the two lines intersect (skill = challenge), which represents a good ow of this level. Finally, during the third level, the challenge was greater than the skill which means that this level was more challenging than the previous ones.

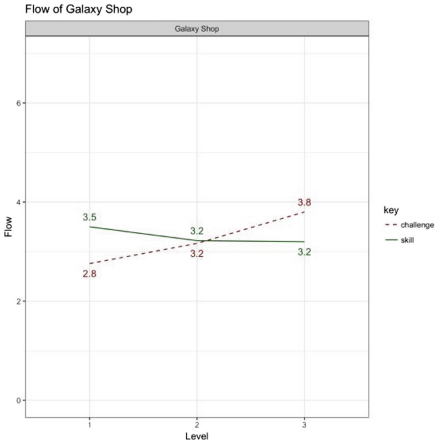

Fig. 3. Skill-challenge results

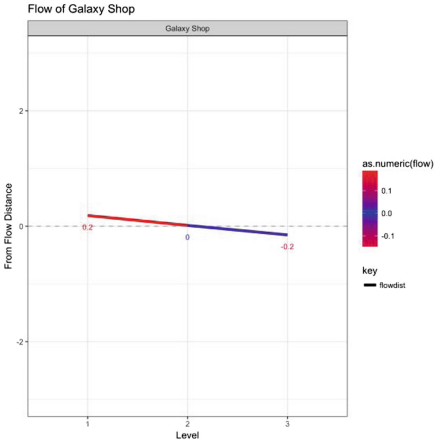

Fig. 4. Far from flow distance

6.4 Learning Gain and Engagement Correlation

One important perspective to investigate in this study was trying to find the correlation between the learning achievement of the participants, and the engagement level that they have experienced during performing the learning activity. The results in Fig. 5 show that there is a correlation between the engagement level of the learners and their learning gain. The group that used the computer-represented as a dashed line- had relatively low levels of engagement and corresponding low learning gain levels. On the other hand, the group who played using the interactive wall had high engagement levels as well as corresponding high learning gain rates. This gives some evidence that the difference in the learning gain between both groups happened due to the difference of the engagement level the participants have experienced, since it is the only changing factor in the experiment.

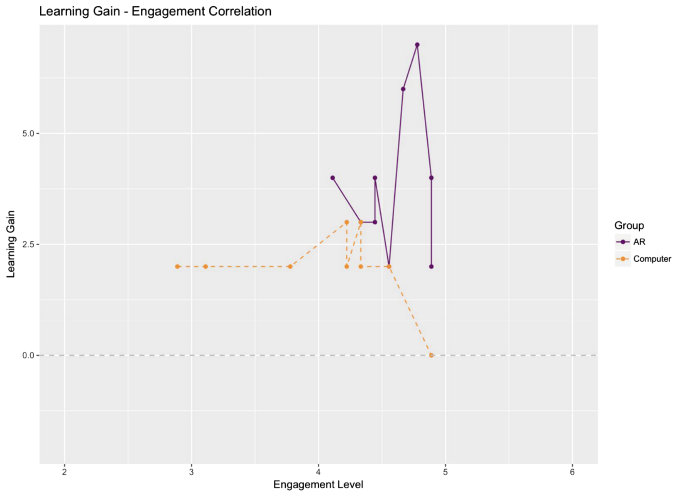

Fig. 5. Correlation between learning gain and engagement

7 Conclusion and Future Work

The usage of augmented reality to build interactive educational systems for educationally challenged learners is a growing research area. The main objective of this study was to examine effect of using AR projection based games as an interactive instructional mean for Down syndrome teenagers. Galaxy Shop is an educational game that was specially designed for Down syndrome teenagers to help them be financially independent during their daily life routine. The game taught them advanced mathematical skills namely addition, subtraction, and multiplication. It consisted of many real-life applications using real Egyptian currency options to give the learner the feeling of managing his own money. Two versions of the game were evaluated and tested with two different groups of participants using two different technological means: interactive wall and computers. The statistical analysis shows that playing Galaxy Shop on an interactive wall inside the classrooms is more effective than playing it on normal computers for the learning gain as well as the engagement levels of the participants.

This might be due to the presence of the interactivity factor that affects the enjoyment level of the learners, and accordingly their learning gain.

Further experiments using different AR based learning means need to be conducted in order to examine the effect of such technologies on the learners. Moreover, Galaxy Shop can be tested on long term bases so that deeper learning and behavioural outcomes can be evaluated. Finally, a concrete test of the correlation between the usability of AR means and the learning achievement of the users, in addition to an experiment that examines the relation between different developmental profiles and gaming preferences are needed.

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