Enhancing Self-Motivation Through Design of an Accessible Math App for Children with Special Needs

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Abstract. The inclusion of learning activities using tablet devices in the classroom environment continues to grow. Unfortunately, this corresponding increase has not correlated with a growth in accessible content for children with special needs. In fact, most children with a reported disability take fewer science and math courses than mainstream students primarily due to the unavailability of information in accessible formats. In this paper, we discuss an educational App that makes math engaging to students while being accessible to children with special needs. We then present a pilot study to collect empirical evidence on how well the app self-motivates the user. Results from the study, which involved thirty-four participants, show significant measures of self-motivation when using the educational math app.

Keywords: Accessible math · Special needs · Gamification · Intrinsic motivation

1 Introduction

Tablet devices are known to provide an interactive experience that has revolutionized learning for children. Unfortunately, while these tablet devices are intuitive to utilize and easy for many children, those with motor limitations tend to have difficulties due to the fine motor skills required for interaction. Thus, as tablet devices are increasingly being integrated into the classroom environment, there is a measurable demographic of school-age children, such as those with motor disabilities, that are not being given equal access [1].

To enable general access to computing platforms, children with motor impairments typically use a physical device, such as a switch, to gain access. Switch types of devices range from hand switches, head switches, foot switches, mouth switches, and even switches that can detect muscle movement. Software applications that enable access through switches to mobile tablets are called switch-accessible Apps. Based on the emerging appeal of tablets, there has been a slow influx of switch-accessible Apps being created [2]. Unfortunately, of the 675,000 Apps listed as native to iPad in October 2014, less than 0.02 % of them were switch-accessible. Despite the popularity of Apps, only a few have considered accessibility, especially in the context of motor impairments [3, 4]. In fact, in a recent survey [5], it was noted that very few Apps could support accessibility with respect to motor limitations - 24 % required two-handed input, 50 % required complex

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surface gestures such as swiping or two-finger pinch, and 10 % used motion gestures—all of which have important implications for motor-impaired accessibility.

Given that the societal adoption of tablet devices continues to grow and access continues to remain unequal for children with movement disorders, our objective is to increase access to educational content for children with motor disabilities that support their goals in the classroom environment. In the K-12 space, approximately 11 % of children between the ages of 6 to 14 have a reported disability [1, 6], and yet these students took fewer science and mathematics courses than those without disabilities. Since these differences are generally due to the unavailability of information in accessible formats [6], our emphasis in this paper discusses the inclusion of math content into switch-accessible Apps for children with motor disabilities. In this paper, we discuss elements of the math App that make it engaging to students while being accessible to children with special needs. We then present a pilot study to collect empirical evidence on how well the app self-motivates the user. Results from the study, which involved thirty-four participants, show that these types of apps are enjoyable and self-motivating based on the Intrinsic Motivation Inventory [7], a validated multidimensional measurement device used to assess participants' subjective experience related to a target activity.

2 Description of Accessible Math Apps

Intrinsic motivation (or self-motivation) is shown to be a vital factor in learning. Intrinsic motivation involves an individual engaging in various learning opportunities because they are seen as enjoyable, interesting, or relevant to meeting one's core psychological needs [10]. There are three inherent sources of intrinsic motivation that have been highlighted by researchers [11] - the need for developing competence, the need for relatedness, and the need for autonomy. With respect to children's learning, the need for developing competence can be achieved by ensuring learning activities are set right above the learner's skill level so that the child feels success after accomplishing a task. For children with special needs, where traditional educational materials are not always provided in alternative, accessible formats, relatedness can be achieved by creating learning activities that are accessible and enjoyable to all, thus creating meaningful connections based on common activities shared with their peers. Autonomy for children with disabilities can be accomplished by ensuring learning materials are accessible based on the student's needs and abilities and thus can be used independently. Students who feel like they have a choice and are provided a sense of control are more likely to engage in the learning activity. Thus, any education app that is designed for children with special needs should incorporate these factors into their design to enhance intrinsic motivation.

In the early child development literature, cause-and-effect refers to a child's understanding that an action can produce a result to control the environment. Through play, a child typically learns the concept of cause-and-effect, which is an important step in their developmental process [8]. For many children with disabilities, purposeful movement across space will not occur until they understand this concept of cause-and-effect. Thus, many special education teachers that use mobile apps with children with special needs, tend to use cause-and-effect apps and/or apps that require visually attending to

objects of interest [9]. As such, we focus on designing accessible math apps based on this cause-and-effect framework that incorporates the three factors for enhancing intrinsic motivation as discussed above. The need for competence is addressed by incorporating different learning settings that can be selected based on the current knowledge level of the child. The need for relatedness is addressed by gamifying the education math app such that it is engaging to all children with or without special needs. The need for autonomy is addressed by incorporating adjustable settings that makes the education app accessible to children with differing abilities.

OctoPlus is a math adaptation of a cause-and-effect gaming app called Turtle Invaders [12]. OctoPlus places the user in an underwater water world where the user has to battle turtles to score points (Fig. 1). OctoPlus reinforces key addition math skills within an interactive gaming environment through the inclusion of both a drill and challenge mode. Through adjustable learning settings (such as a beginner, advanced, and expert mode), students can learn and be assessed based on their own individual learning skills. OctoPlus is also switch-accessible and is designed to enhance motor skills for young children and kids with motor or cognitive delays. OctoPlus incorporates the common core math standards associated with Operations and Algebraic Thinking, namely:

- CCSS.MATH.CONTENT.K.OA.A.3 - Decompose numbers less than or equal to 10 into pairs in more than one way
- CCSS.MATH.CONTENT.K.OA.A.4 - For any number from 1 to 9, find the number that makes 10 when added to the given number
- CCSS.MATH.CONTENT.K.OA.A.5 - Fluently add and subtract within 5.

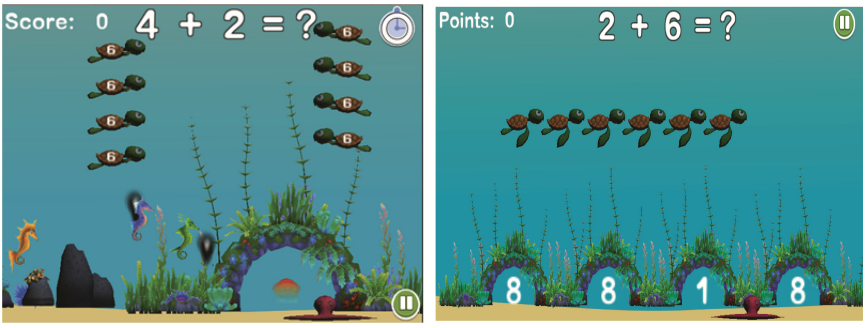

Fig. 1. OctoPlus Game Scenes. The left image shows the OctoPlus Drill Mode in which different equations that add up to the same number are sequentially presented. The right image shows the OctoPlus Challenge Mode at the beginner level in which the user must select the correct answer to solve the equation.

ZyroMath City Count is a math app based on the runner game concept. The runner game concept is simple; you run until you die. Despite its simplicity, runner games are among the most popular gaming Apps on mobile devices. ZyroMath City Count places the user in a city environment where the user must jump to collect stars to score points,

while also jumping over obstacles to survive (Fig. 2). Just as with OctoPlus, ZyroMath is designed to be switch-accessible and accessible to children with motor or cognitive delays. ZyroMath City Count incorporates the common core math standards associated with Counting and Cardinality, namely:

- CCSS.MATH.CONTENT.K.CC.A.1 - Count to 100 by ones and by tens
- CCSS.MATH.CONTENT.K.CC.A.2 - Count forward beginning from a given number within the known sequence
- CCSS.MATH.CONTENT.K.CC.A.3 - Represent a number of objects with a written numeral 0-20 (with 0 representing a count of no objects)

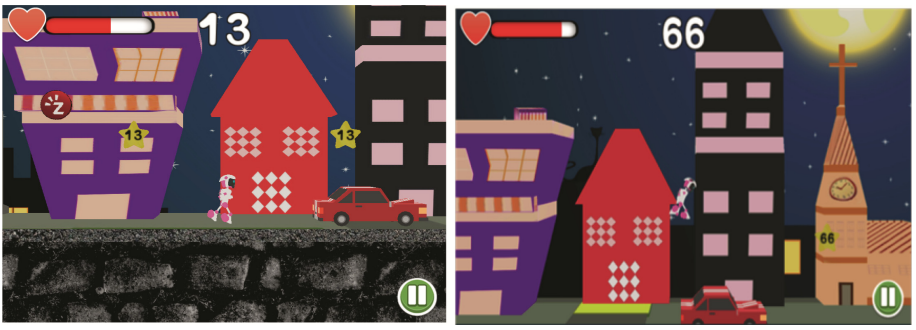

Fig. 2. Example of the ZyroMath City Count Scene, where the user must jump to collect stars to count and earn points.

In addition to being switch-accessible, each app employs a settings menu that provides the ability to adjust game settings based on the needs of the child, such as slowing or speeding up the game avatars or removing the background to improve attention (Fig. 3).

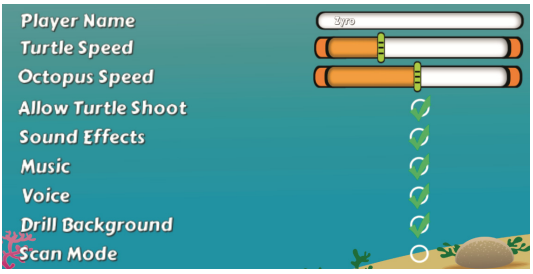

Fig. 3. Adjustable game settings for the OctoPlus math app allows, for example, changing the speed of the game characters or removing background, voice, or sound effects.

3 Experimental Setup

To evaluate self-motivation of users when using the accessible math gaming app and confirm that the factors we selected in the design can enhance intrinsic motivation, we employ the Intrinsic Motivation Inventory (IMI) instrument [11], which has been used in several experiments related to intrinsic motivation and children [13, 14]. In IMI, the interest/enjoyment subscale is considered the self-report measure of intrinsic motivation; thus, it is the only subscale we use in this study.

3.1 Participants

Thirty-four (34) adult participants were recruited and the study conducted using Amazon's Mechanical Turk service. In prior studies, Mechanical Turk was shown to provide a sufficiently diverse participant pool necessary for conducting high-quality studies involving human participants [15, 16]. Three different math games were selected for play and randomly assigned. The opening instructions provided were as follows:

> *We are studying how accessible math games can motivate children with special needs. The results from this study will enable us to design more effective mobile applications for children with disabilities. In this study, you will play two iterations of a math game. It shouldn't take you any longer than 10-15 min. After playing the games, you will need to fill out a survey.*

3.2 Testing Scenario

There were three different math games employed in this study – *You Do the Math*, *OctoPlus*, and *Math Game*. Group 1 (*G1*) was randomly assigned to play the math game called *You Do the Math* (Fig. 4) in which each participant used a calculator-type interface to answer addition equations. Group 2 (*G2*) was randomly assigned to play the accessible math game *OctoPlus* in which each participant had to answer addition equations by shooting turtles when in the arch with the correct answer (Fig. 1). Group 3 (*G3*) was randomly assigned to play the math game called *Math Game* in which each participant answered addition equations by selecting the correct answer via touch (Fig. 4). For these game scenarios, the math equations focused on adding two numbers, summing up to 10.

Participants in each group played two iterations of their game. The self-report measure of intrinsic motivation was calculated based on the interest/enjoyment subscale of the IMI, as shown in Table 1. The score for the IMI instrument is calculated by first reversing the score of the items for which a (*) is shown in Table 1 and then using the resulting number as the item score. The self-report measure of intrinsic motivation is then calculated by averaging across all of the items on that subscale.

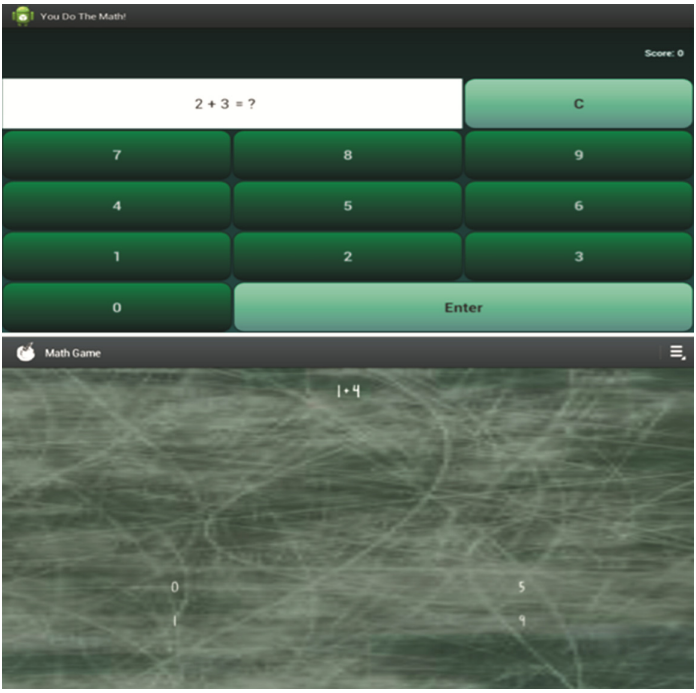

Fig. 4. Top image – Game scene from the *You Do the Math* app; Bottom image – Game scene from the *Math Game* app.

Table 1. Interest/enjoyment subscale of the Intrinsic Motivation Inventory. This subscale is considered the self-report measure of intrinsic motivation.

	1 not at all	2	3	4 somewhat true	5	6	7 very true
I enjoyed doing this activity very much							
This activity was fun to do.							
I thought this was a boring activity. (*)							
This activity did not hold my attention at all. (*)							
I would describe this activity as very interesting.							
I thought this activity was quite enjoyable.							
While I was doing this activity, I was thinking about how much I enjoyed it.							

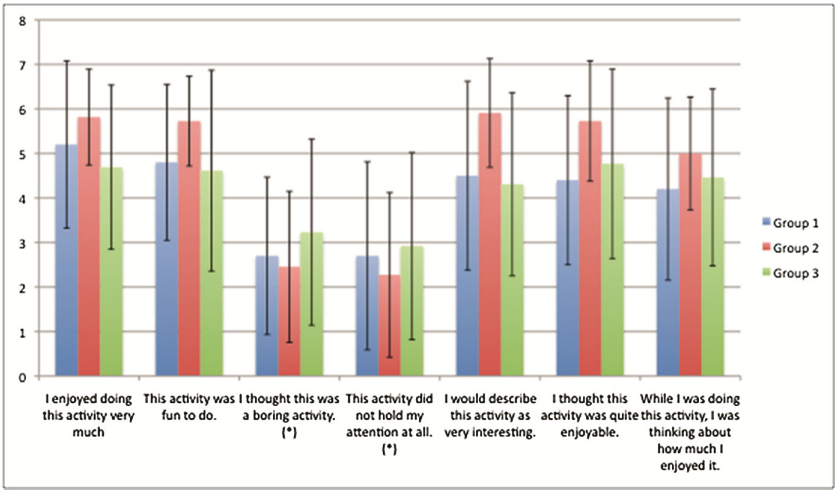

Fig. 5. Decomposition of participant averages for the interest/enjoyment subscale of the IMI used to assess self-motivation.

Table 2. Study statistics correlated with evaluating intrinsic motivation associated with each of the math gaming apps.

	Group 1 - *You Do the Math*	Group 2 *OctoPlus*	Group 3 *Math Game*
Age			
<21	1	1	2
21-30	6	6	6
31-40	3	4	5
Gender			
Male	7	8	10
Female	3	3	3
No. Participants	10	11	13
Avg. Time Played (min)	8.7	17.6	14.0
Average IMI Score	4.81	5.64	4.67
Stdv IMI Score	1.75	0.97	1.70

4 Results and Discussion

The focus of this study was to evaluate self-motivation of participants when using the accessible math gaming app and confirm that the factors we selected in the design can enhance intrinsic motivation. The primary goal was to determine whether the game attributes incorporated to address the needs for competence, relatedness, and autonomy had a positive effect. Figure 5 decomposes the scores for each of the items in the interest/enjoyment subscale of the IMI whereas Table 2 provides the summary statistics on each of the participant groups.

Based on the survey results, the accessible math game resulted in higher intrinsic motivation than the other two math games (Table 2). With respect to the individual subscale items, participants seemed to have more enjoyment when interacting with the OctoPlus math app $\{mean(G1) = 5.2; mean(G2) = 5.8; mean(G3) = 4.7\}$ and were less bored $\{mean(G1) = 2.7; mean(G2) = 2.5; mean(G3) = 3.2\}$. Of interest to note is that, even though the average time spent doing two iterations of the game was longer in duration than the other two, participants still felt that the OctoPlus activity was more fun to do $\{mean(G1) = 4.4; mean(G2) = 5.7;\ mean(G3) = 4.8\}$. Although, based on the sample size, these results only indicate trends in the data, it does show some evidence that the accessible math app can enhance self-motivation in participants.

5 Conclusions

The pilot study discussed in this paper was designed to investigate elements of an accessible math app and collect empirical evidence on how well the app enhances intrinsic motivation. Although the study involved adult participants, this work lays the foundation in understanding how an accessible math app can be designed to address the needs of competence, relatedness, and autonomy. To further build an evidence base, future studies will expand to include children and children with various disabilities. Another future study will also investigate the impact on math skills and whether gains in math knowledge are achieved. These future studies are necessary to fully validate the effectiveness of math education apps, especially with respect to engaging children with disabilities in additional learning opportunities.

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