SEE ME ROAR: Self-determination Enhanced Engagement for Math Education Relying On Augmented Reality

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Abstract

Contemporary primary school students generally spend a lot of time playing digital games, but may be less interested in their schoolwork, such as learning mathematics. Mathematics includes many abstract concepts that can be difficult to grasp for some students. Augmented reality as a technology makes it possible to transfer the abstract knowledge into concrete and situated contexts so that the students can better comprehend the information. In addition, the social interactions can also improve the students' learning experience. In order to better understand how to design such AR games for learning, we design an AR-based social game platform for primary school students in mathematics learning, called SEE ME ROAR. This paper describes the design and implementation process of the first prototype. We report early results from one primary school teacher and two primary school students, which indicate the game is fun and might be helpful for their study. Future work will focus on the specific effects of different game mechanics on the students' learning experience. The game platform will become more generalized for other subjects in the future.

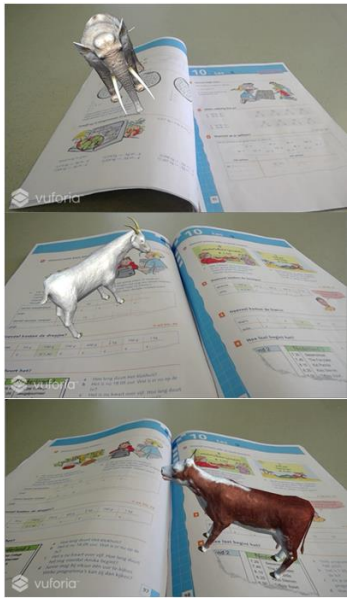

Figure 1: The screenshot of augmented animals on different pages.

Author Keywords
Augmented reality; serious game; mathematics learning; game design; game.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Artificial, augmented, and virtual realities.

Introduction

The current generation of students is growing up in the age of information and communication technology. They spend a lot of time and show great interests in playing digital games and interacting with each other through mobile technologies, more often than previous generations [12]. Because games revolve around learning, and additionally afford experiences that would be infeasible in the real world, it has often been hypothesized that they can be used to engage and motivate students in learning [5].

Primary school Mathematics involves a number of abstract concepts, such as notations, numeric operations, conceptual relationships, and so on [4]. It might be difficult for some students to understand the abstract information.

Augmented reality (AR) is a technology that can connect the real world and the virtual world by overlapping virtual objects onto the real world objects [1], making it possible for students to understand invisible concepts or content from the textbook by situating the concepts in a concrete context, or by visualizing objects that are impractical for students to have access to in real life [4].

In addition, mathematics performance is predicted by student motivation [2], with especially girls in primary schools experiencing lower perceived competence and engagement [10]. Because games are considered motivating and can help improve a student's perceived competence [20], they may improve motivation and cognitive effort, and thereby performance, for at risk students.

Students learn with the collaboration of their classmates, the support from their teachers, and the encouragement from their parents [8]. The social interactions can influence students' engagement and performance in learning. Therefore, effective social interactions have to be addressed in facilitating students' learning experience [9].

While games for learning have been shown to be more effective than traditional forms of instruction, there is little proof for their motivating qualities. This is among others due to a lack of research on how to design these games [21]. Although numerous AR-based digital games for learning have emerged recently, this problem is even greater for these kinds of games due to their relative newness. In addition, not much of the AR-based digital games are focused on traditional educational settings (e.g., school textbook and homework).

Therefore, we are designing an AR-based social learning game for primary school students aged from 7 to 8 called SEE ME ROAR. In the game, there are virtual animals hidden throughout the textbook that have different eating habits. Students can look for the 3D animals by using the mobile devices to scan the textbook. See Figure 1. They can find more than 20

animals, and then play with them, feed them with food, answer their questions related to their mathematics textbook to collect them into their farms. The final animal in the game is the lion, which is the king of the animal kingdom. During the play, students can also compete or collaborate with each other. The main purpose of SEE ME ROAR is to improve students' learning experience by engaging in the game play and interacting with others.

Currently we are focusing on mathematics learning, however, we believe that the platform can be generalizable to a variety of other subjects in the future. More elements will be illustrated in the following sections.

Related Work

Numerous existing studies focusing on AR-based learning games have emerged in the past decade. Some of the studies have shown positive effects of AR-based learning games on students, which can be classified into three main categories, learning achievement, motivation, and social effect.

Learning Achievement

Learning achievement refers to the effective results in achieving learning gains in terms of learning concepts and content. Lu & Liu [16] have designed an AR marine learning program for primary school students and indicated that the AR program specifically helps the students improve learning performance. Chen & Tsai [6] have developed an AR system for library knowledge education and demonstrated that the AR system could improve students learning performance significantly.

Motivation

Motivation involves the enhancement in engagement, satisfaction, or fun experiences that motivate students in learning. Bressler & Bodzin [3] have shown that the AR game could make the learning more interesting for students. Another study on an art course has also shown that the AR is better in motivational factors of attention and satisfaction compared with slides-based learning method [7]. Lee & Lee [15] have developed an AR-based mathematical education game, which could increase the enjoyment of students' learning experience as they have fun during the game.

Social Effect

Social effect is the advantage of AR related to students' interactions with classmates and teachers [1]. One of the previous studies has integrated AR into environmental education and found out that the use of AR technology provides more opportunities for students to collaborate and communicate with each other [13]. The AR-based game for 21st century skills, RtR, can encourage students' social interactions [19].

Attention has been attracted to the study of AR-based learning games. However, many aspects have not been addressed sufficiently. First of all, most of the current AR learning games is designed based on outdoor playing or a classroom environment. However, limited attention has been paid on the home learning environment, which may effectively encourage students to learn spontaneously. Secondly, as mentioned above, there's a need for more understanding as well as common design strategies on how to design motivating and effective AR games for learning. It is important to identify the different outcomes and effects of each factor in order to amplify the advantages of AR-based

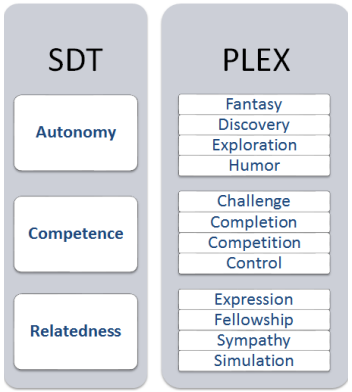

Figure 2: The framework of mapping the SDT and the PLEX.

Figure 3: The avatars selected for the game.

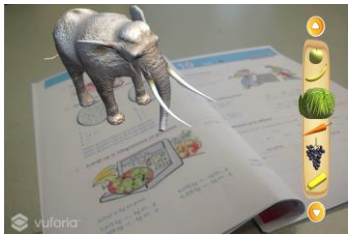

Figure 4: Exploration with the animals.

learning games to help students enjoy a better learning experience. Last but not least, some of the studies have been designed without involving the target group. Game designers and researchers are often removed from the perception and interests of children by some years. We contend that games can be made more engaging by involving the target learner group in the design process at an early stage and have them participate in the design process of the game concepts.

Game Design

In order to study the effects of different factors in AR-based social learning games, the Self-Determination Theory (SDT) and the Playful Experience Framework (PLEX) are used. The SDT includes characteristics of students' needs for autonomy, competence, and relatedness [11], which can enhance the self-motivation and result in more engagement, effort, and high-quality performance [11]. The PLEX framework summarizes categories that users might experience during game play [11, 14].

The research approach is to first map the PLEX framework to the SDT: The playful experience of discovery, exploration, fantasy, and humor will be mapped to autonomy. The playful experience of challenge, competition, completion, and control will be mapped to competence. The playful experience of expression, fellowship, simulation, and sympathy will be mapped to relatedness. See Figure 2.The second step is to design the structure of SEE ME ROAR based on the framework.

Autonomy

The autonomy within the SDT refers to the feeling of volition or willingness to do a task [17, 18]. The experience of autonomy is high when the task is done for personal interests or values [18]. In SEE ME ROAR, the students are encouraged to choose and explore freely to increase the autonomy.

- **Fantasy**: Students can choose their own avatars in the beginning of the game, which will represent themselves during the game. They can change the appearance of their avatars according to their preferences. The avatars are the existing models from the Unity Asset Store for now. See Figure 3. New characters in the game will be designed in the future.
- **Discovery**: Students scan the textbook with the digital devices freely to discover animals hidden in the book. More than 20 different animals will show up with different chances. Designers will preset the chances based on their species. For example, the rabbit will appear frequently, while the tiger will only show up for a few times.
- **Exploration**: Students interact with the animals they see and explore their reactions. They can touch the animals, walk the animals around, and choose food to feed the animals. Different animals have different preferences of the food and students need to find out the animals' favorite food. See Figure 4.
- **Humor**: The animals will do interesting animations to response the students' interaction. They also have funny sound effects within the animations.

Competence

The competence is the need for challenge and feeling of completion [17, 18]. The activities like to acquire new knowledge, to be challenged in a optimal way, or to receive positive feedback, can enhance the feeling of

Figure 5: The animal is satisfied with the food (top) and gives the student a mathematics exercise (bottom).

Figure 6: The feedback and reward after the exercise.

competence [18]. In SEE ME ROAR, the students are challenged with mathematic exercises and receive immediate feedback from the game.

- **Challenge**: Students get a mathematics exercise from the animal if the animal is satisfied with the food. In this early prototype, the exercises are related to the mathematical content in the textbook page. See Figure 5.
- **Completion**: Students receive immediate feedback after finishing the exercise. If the exercise is answered correctly, the students will get a reward in the form of food. See Figure 6.
- **Competition**: Students can see the rank list of the exercise. The rank list is given by the answering time.
- **Control**: Students have a collection of all the animals they find in the book. They can check their current animal collection in their own farms and see what other animals they can find in the textbook.

Relatedness

The relatedness within the SDT concerns the experience of feeling connected with other people [17, 18]. In SEE ME ROAR, the social interactions among students are enabled to produce the feelings of relatedness.

- **Expression**: Students can change the facial expression of their avatars to express their feelings, including happiness, sadness, and so on. Students can check each other's facial expression on avatars.
- **Fellowship**: Students can play the game with classmates face-to-face by scanning the textbook together and see the animals on their devices.
- **Sympathy**: Students can exchange the food with classmates. They can use their current food to exchange for other types of food.
- **Simulation**: Students who finish the game can take a picture of themselves with lion manes, which can then be printed out and framed in the classroom.

Early Process, Implementation, and Feedback

In the design of the first prototype, we have applied the participatory design method in order to involve the target students from an early process and thereby increase the possibility that our game concepts would be accepted and liked by the age group.

Two primary school students aged 7 have been invited to co-design with us in the design process. The purpose of the co-design is to get useful information to improve the design of the game. The students could express their thoughts on the game design, and share their own ideas about the game. See Figure 7.

We have conducted four co-design processes, where each one took around 45 minutes. In the first co-design process, we tried to get familiar with the students and understand them better. We asked them the types of digital games they would like to play and found out that they like games such as "Clash Royale", "SimCity", and "Minecraft". The students told us they would spend 1.5 hours to 3 hours on playing games at home on school days, while on the weekend the playing time might be longer. In the second co-design process, we encouraged the two students to draw the elements they would like to see in a game. One student drew an elephant with water and food around it. The other

Figure 7: Co-design process with two primary school students.

student drew a small farm and tall buildings, expressing that he would like to do some trade by planting vegetables and raising animals in the farm in order to upgrade his buildings. Their drawings and thoughts have provided us the source of the game ideas. In the third co-design process, we collected the preferences of students in avatars, animals, and rewards. Students would like to use current characters in "Clash Royale" to represent themselves, see animals like a tiger, lion, elephant, or dog, as well as get more food to feed the animals as a reward. In the fourth co-design process, we showed the SEE ME ROAR to the two students. They had different choices regarding the avatars. One student said: "Actually some of them are really cool, I want to choose several of them". Students were excited to see the animals walking around on their book. They used the word "cool" several times. When asked about what they wanted to do with the animals, the students said they wanted to see the animals to do some tricks, like an elephant playing with a ball. When they received the exercise from the animal, they thought the exercise was quite easy for them to answer. It might be more effective if the exercises have different difficulty levels. One of the students really liked the ranking. He said, "the ranking is nice, I want to know my position". Regarding the animal collection, both students said they liked it and also wanted to see more animals in the game.

We also showed the game to one primary school teacher. The primary school teacher said that students might have difficulties in understanding the abstract concepts in counting, timetable, and so on. Therefore, AR is indeed a good way to make mathematics more concrete and easier for them to learn. The teacher described SEE ME ROAR as "looks cool", "good idea", and "helpful". The teacher also mentioned that it might be a good idea to involve other subjects, such as history and geography, into the game.

Conclusion and Future Work

We designed and made a first prototype of SEE ME ROAR, an AR-based social learning game. The game is focused on helping primary school students engage in mathematics learning and interact with their classmates. We used Unity 3D as the game engine to build the game, with the Vuforia plugin for AR features.

We have divided SEE ME ROAR into three levels based on SDT and PLEX framework, which are autonomy, competence, and relatedness. In the future, we plan to follow a practice led approach to developing the game and instructional design, where the base prototype is modified to include these new levels. Through this design and implementation process we seek to chart the design space of AR games for learning, investigate questions regarding the nature of the magic circle in an AR setting, the influence of competence, autonomy and relatedness stimulating game mechanics on motivation and learning, the role of endogenous fantasy, et cetera.

Currently the learning subject is mathematics for students aged 7 to 8. We plan to make the game a generalized platform and different subjects all can use this platform.

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