Development of a Game-Based and Haptically Enhanced Application for People with Visual Impairment

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Abstract. The objective of this study is to develop educational games for people with visual impairment to learn science in a fun and interactive method (i.e., a serious educational game). The paper comprises investigations of the effect of tactile feedback and collaboration on the game for visually impaired users within the framework of game-based science learning (GBSL). Results showed significant effects of tactile feedback and collaboration on participants' presence and immersion levels. The research will enhance the future development and application of game-based science learning.

Keywords: Game-based science learning · Tactile · Collaboration · Visual impairment

1 Introduction

Serious Game is defined as application fields that are related to many sectors overall such as health, defense, education, and training and is still expanding. As classified by Alvarez, a Serious Game addresses a set of fields: Educational games, Simulation games, Edutainment, Digital Game Based Learning, Immersive Learning, Social Impact Games, Persuasive Games, games with an Agenda [1]. The connection between playing video games and enhanced cognitive abilities are stated to be beneficial for students. However, the characterization of video games and why playing those leads to improved abilities has not been resolved [2, 3]. These video games contain several common properties: randomness, speed, high perceptual, cognitive and motor load, and decision-making skills. Many action video games contain violent content, making their suitability for children questionable. Hence, there is a need to investigate and experiment on non-action games and the beneficial factors for the children. In addition, not much research has been conducted about the cognitive benefits of non-action video games [4]. Although, fun and entertainment generally attract people to games, the engaging learning experience of game playing is contributed by the effective game principles embedded in game designs [5]. There are already a number of educational games created for science learning. But, the complexity of problems and tasks in the games are either too simple or too complex to solve.

The objective of this research is to develop educational games for the visually impaired people to learn science in a fun and interactive way rather than the traditional

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learning method. With a low-fidelity game demo and an interesting topic (Astronomy), the paper will answer the following questions: Is the presence and immersion levels higher among players with collaborative play compared to individual play? How effective is tactile feedback in comparison to non-tactile feedback condition?

2 Literature Review

2.1 Game-Based Science Learning (GBSL)

To demonstrate the potential of educational games for science learning, Clark summarized the results found in studies into four learning aspects: 1. conceptual and process skills learning, 2. epistemological understanding, 3. attitude, identity, and motivation, and 4. optimal structuring of games for learning [6]. Although the findings from these studies promise a future for game-based learning in science education, there is a lack of comprehensive evidence to support the effectiveness of this new learning technology [7]. Even though there is a research trend in game-based learning, with studies in science learning increasing [8], this area of research is still relatively smaller. In addition, most of the published review studies of game-based science learning mainly focused on the learning effectiveness or the outcomes classifications [6, 9]. On deeper research, two other important aspects seemed to be overlooked by previous studies were also explored. First, the way how games were designed and implemented. Second, the pedagogies or instructional designs embedded in the games that play a critical role to make learning more effective [5, 10]. Concluding from the data collected about GBSL from multiple other research, only few studies provided review on aspects other than learning outcomes such as game genre, purpose of game, study design, learning domain, and target learners [8]. This paper focuses on the game design and implementation.

2.2 Factors Effecting Game Design

Collaborative Learning. In these types of games, players can communicate with each other to solve problems and collaboratively achieve individual and group goals [10]. Collaborative virtual environments may be used successfully to improve the acquisition of abstract concepts.

Multiplayer games have learning potential, and studies focus on which types of learning these games support. The key element in multiplayer games is: the interaction between players to collaborate and communicate in the game [11]. The main attribute of this study is that the development of multiplayer educational game constructed as complex social environments, where students collaborate and learn through numerous interactions among other subjects, objects and tasks of the game, under specified rules. However, these factors has not been considered thoroughly and not enough research has been done on this factor for the visually impaired. Most researchers are restricted to multiplayer gaming among sighted players. Paraskeva et al. argues that multiplayer educational games can be a promising educational tool, an alternative to the current multiplayer gaming, which will promote collaboration among students [12].

Tactile Feedback. The most common expectation to be fulfilled by tactile feedback is to enhance the perception of virtual reality rendered by visual and auditory displays in medical, entertainment, education and military applications [13]. Combined with sound, haptics can create a viable alternative interface for blind and visually impaired people. However, according to Morris, et al. [14], players-particularly players who had limited experience using the Phantom (haptic), initially found the six-degree-of freedom input difficult to control. Moreover, players showed the tendency to make movements that can potentially damage the (expensive) haptic devices. This was because the haptic and game were immersive and the players were not treating the device with normal care. The rapid motion of the device caused damage to the devices.

Previous research supports the use of tactile feedback for the visually impaired to perform better. However, there are still significant human interface challenges associated with tactile feedback that has not been explored by existing games.

3 Methodology

3.1 Participants

Eight participants from Lamar University (with the age between 20 to 30 years old) were employed in the experiment. As the target group are students who are visually impaired, all the participants were blindfolded while performing the experiment. They were provided with written, informed consent form.

3.2 Independent Variables

Tactile Feedback. There are 2 levels: Tactile feedback and Non-Tactile feedback. In the tactile feedback condition, players are given representational models made from Play-Doh while performing the tasks. In the non-tactile feedback condition, players will not be given any representational models while performing the tasks.

Collaborative Mode. There are 2 levels: Individual Play and Collaborative Play. In the Individual Play condition, players play the game alone and in the Collaborative Play condition, players have a companion to collaborate, communicate and share the tasks in the game.

3.3 Dependent Variables

Presence. It is defined as a state of mind in a virtual environment experience. In this study, presence is used to measure how interactive and motivating are the game and its game features in serious educational games.

Immersion. Immersion is defined as being deeply involved in a given task. In this study, immersion is used to measure the involvement and engagement of a player when playing the serious educational game.

Dependent variables were measured by a questionnaire using Likert-type seven-point scales, in which 0 meant ‘not at all’ and 7 meant ‘a lot’. The questionnaire focused on the users’ evaluation of their own task performance when using the system, how well they understood the system, and to what degree they felt that they learned how to use the system, as well as their skill level in using specific features in the system.

The Cronbach’s Alpha (α) for the presence questionnaire and immersion questionnaire in all 4 conditions are as given in the table below. Cronbach’s Alpha was calculated to derive the correlation between the questionnaire items. The Alpha values from the 4 conditions clearly showed that the questionnaire was reliable (Table 1).

Table 1. Cronbach’s Alpha for 4 given conditions

Condition	Presence (α)	Immersion (α)
IP, with TF	.72	.79
IP, without TF	.83	.75
CP, with TF	.73	.76
CP, without TF	.75	.80

3.4 Equipment

Low-Fidelity Prototype (LFP). This is the initial raw presentation of the ideas and requires less time, less specialized skills and less resources. The purpose of building a LFP is not to impress the users or the end product, it basically gives us an insight of the demo. This game’s LFP was designed by using paper prints, plastic toys and Play-Doh. It also included eye-patches to blindfold (Fig. 1). Other equipment include Measurement Tool and End-user questionnaire.

Fig. 1. Low-Fidelity Prototype of an educational game developed by the authors

3.5 Tasks

The task is to clear the misconceptions by completing the game and the challenges designed in it. A single dice is rolled for movement in each turn. Some tasks had easy riddles, quests and identifications. The task is directly linked to its respective misconception. In the collaborative mode, participants were asked to play collectively as a team.

3.6 Procedure

At first, the participants were requested to fill in the demographics questionnaire. Then, participants were asked to review their respective material and instructions. All participants were blind-folded during the entire experiment. The participants played the game on the LFP and completed all the tasks. During the play the participants were under observation and assisted whenever required. In the end, the participants need complete a post-questionnaire. The whole experiment last around 1 h.

4 Results

A 2 × 2 ANOVA was conducted to analyze the data. The following table (Table 2) summarized the results of the statistical analysis.

Table 2. Significant effect for performance measures

Dependent variable	Effect	F-value	P-value
Presence	Tactile feedback	29.30	0.0010
Presence	Collaborative mode	98.19	<0.0001
Immersion	Tactile feedback	6.09	0.0430

4.1 Presence

The analysis revealed a significant main effect of collaborative mode ($F_{1,\ 7} = 98.19$, $p < 0.0001$) and tactile feedback ($F_{1,\ 7} = 29.30$, $p = 0.0010$). Post hoc analysis showed that the participants' presence in collaboration mode ($M = 28.68$, $SD = 1.74$) was significantly higher than that in individual mode ($M = 21.87$, $SD = 3.28$). The participants' presence in tactile feedback condition ($M = 26.93$, $SD = 2.90$) was significantly higher than that in non-tactile feedback condition ($M = 23.62$, $SD = 4.92$).

4.2 Immersion

Results revealed a significant main effect of tactile feedback ($F_{1,\ 7} = 6.09$, $p = 0.0430$). Post hoc analysis showed that the participants' immersion in tactile feedback condition ($M = 27.43$, $SD = 2.98$) was significantly higher than that in non-tactile feedback condition ($M = 25.06$, $SD = 3.47$).

The effect of collaborative mode was not significant ($F_{1,\ 7} = 1.78$, $p = 0.2234$). Post hoc analysis showed that the participants' immersion in collaboration mode ($M = 27.06$, $SD = 2.40$) is slightly higher than that in individual mode ($M = 25.43$, $SD = 4.09$).

5 Discussion

Previous research predicts and supports that if the immersion and presence levels are higher, players gain an interest to learn: which includes science and other educational topics. Feedback from the students to the questionnaire items confirms to what has been indicated by researchers, that educational games are able to create enjoyable and realistic learning environments for learners to acquire abilities and establish their knowledge in the process of playing games, so that they can further apply the knowledge and skills to relevant games as well as to real-world scenarios.

5.1 Effect of Tactile Feedback

Results from the analysis showed that tactile feedback had a significant main effect on presence and immersion. Previous research had limitations. For example, no synthetization of tactile feedback in serious educational games for properties as surface roughness, textures and temperature. However, in this research the tactile feedback was implemented and received valuable feedback from the participants. The game design was based on a Low-Fidelity Prototype and Play-Doh was used to induce various in-game features, such as temperature, size, weight and portability. Due to this, participants were able to complete the tasks more efficiently when compared to the condition without tactile feedback. As stated by Burdea, the effects of tactile feedback helped in enhancing the perception of virtual reality in the educational game and also aided friendly learning environment [3].

5.2 Effect of Collaborative Mode

Results from the analysis showed that collaboration mode had a significant effect on presence. Dickey and Manninen described that the key element in multiplayer games is the interaction among players in the game helps in collaborating, communicating, solving problems and learning [6, 11]. In this research, players communicated with each other to solve the tasks and also discussed about the topic on whatever information they previously gained. When players were playing in the individual mode, they showed lesser interest in continuing the game and talked less than the players in collaborative play. The participants learnt more new information during their interaction sessions in the game. These learning aspects were achieved as the players performed the game in an enjoyable way. Also, they were so immersed in the play that most of the students lost track of time while playing the game.

6 Conclusion

The study evaluated the effect of collaborative mode and tactile feedback on GBSL. The results showed that the participants' presence and immersion levels were significantly higher in tactile feedback conditions. Also, the presence level was significantly higher in collaborative play. On an over-all scale of the presence and immersion levels, the best condition with the highest mean scores was the condition with tactile feedback in a collaborative play. Most of the players solved the tasks more efficiently in the tactile feedback condition because the differences were notable. Such notable difference was caused due to the use of Play-Doh under different conditions such as, heat, cold, weight and size of the representational models.

The collaborative play with tactile feedback immerses the players in a collaborative virtual environment and enhances their efficiency performing the tasks. Therefore, learners are able to establish knowledge through the game-based learning activity and to promote their learning motivation to actively participate in learning.

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