On the Design of Embodiment-based Gamification Activities for Learning Fundamental Projectile Motion

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Abstract: Based on theories of embodied cognition, this study applied technologies of natural user interface to design gamification activities for learning fundamental projectile motion. The embodiment-based design facilitates elementary learners to learn the abstract concept of fundamental projectile motion through their body-moving experience. When the learners perform gamification activities with their body movements, they can construct their knowledge schema through external perceptions. This study recruited 60 fourth to sixth grade students to participate the experiment. The participants were randomly and equally divided into body-moving learning group and finger-touching learning group. The learners in the body-moving learning group directly use their body movements to accomplish the gamification learning activities. On the other hand, the learners in the finger-touching learning group have to hold a tablet PC and use only their fingers for all operations. Participants' learning performance was evaluated through tests of factual knowledge and procedural knowledge. The result shows that the body-moving learning group outperformed the finger-touching learning group on speed in the factual knowledge test and projectile angle in procedure knowledge test. No significant difference was found in the rest of test items.

Keywords: Embodied cognition, embodiment-based learning, natural user interface, elementary gamification activities, projectile motion

1. Introduction

Literature of embodied cognition suggests that human cognition consists of mental model simulation, environment, situated action and bodily state (Barsalou, 2008, 2010; Lankoski & Järvelä, 2012; Rambusch, 2006). Learning with the support of body movements, external perception, and environment information is helpful for internal knowledge construction (Arjoranta, 2013; Barsalou, 2010). Pointing gestures, representational gestures, and metaphoric gestures can be exploited for enhancing memorization and improving comprehension (Martha W. Alibali & Nathan, 2012). Macedonia, Müller, and Friederici (2011) found that iconic gestures can better facilitate language learning than meaningless gestures. Currently, learners usually interact with most learning systems through physical controllers and mobile devices such as mouse, smartphone and tablet PC. However, the controller-based interaction is limited to provide enough external perception for a clear understanding when learning abstract concepts in natural science subjects.

Previous research suggests that learning with adequate strategies and technologies can facilitate learners' comprehension of abstract concepts, knowledge construction, and learning performance improvements. Educational computer games can motivate learners, draw their attention on learning content, and improve their learning outcome (Cagiltay, 2007; Tüzün, Yılmaz-Soylu, Karakuş, İnal, & Kızılkaya, 2009). For example, Sung and Hwang (2013) designed a collaborative game with a grid-based Mindtool for elementary school students to learn characteristics of plants and the learners obtained improved learning achievement. The learners' attitudes, motivation, academic record, and self-efficacy were better promoted after playing the game. Howison, Trninic, Reinholz, and Abrahamson (2011) utilized Wii Remote controller to provide gesture-based interaction between learners and learning system and help the learners learn the concept of numerators and denominators. Learning with such kind interaction by using body movements can help learners deal with the cognitive conflict between their thoughts and observational operations for better comprehension. Hao et al. (2010) utilized a webcam to develop a Wii-like, vision-based motion game for learning the stroke order of Chinese characters. The result shows that learners can memorize well the stroke order of Chinese characters and achieve better learning outcomes. The interaction between a learner and a learning system is depended on the design and representation of learning materials. Also, simulation is a form of interactive multimedia. For example, a virtual laboratory can be created and simulated for an experimental process without imposing any physical dangers on learners (Annetta et al., 2014).

Learners can have authentic understanding if they actually conduct a natural science experiment and experience everything that occurs with their own bodies during the experimental process. From the perspective of embodied cognition, external perception and internal mental model simulation both contribute to create cognition. Learning by doing is a practical method and can make learners situate in a rich context. During the learning process, learners' body movements can help them to understand the learning content with a reflection of previous learning and daily life experience (Anastopoulou, Sharples, & Baber, 2011; Shapiro, 2014). For example, with the body participation, multimedia materials, and simulation exercises, learners can successfully bridge the gap of abstract concept and real world to learn fundamental optics better (Hung, Lin, Fang, & Chen, 2014). Chao, Huang, Fang, and Chen (2013) successfully improved learners' memorization of English vocabulary and phrases by using a gesture-based learning system. Kuo, Hsu, Fang, and Chen (2014) implemented total physical response (TPR) approach with an embodiment-based design to facilitate English vocabulary learning. The result shows that the retention of the learners in the embodiment-based TPR group was better than those in the conventional TPR group.

This study applied technologies of natural user interface to design gamification activities for learning the fundamental projectile motion of physics. Another aim of the study was to test if the learners are able to transform what they have learned into real-life practices and applications.

2. System Design

Projectile is an object projected by external force. Projectile motion describes the process regarding how the projectile moves, and it can be easily observed in people's daily life. In this study, the learning content is fundamental projectile motion of physics including two learning goals. The first one is how the projectile parameters change in terms of the moving distance and the angle when the initial speed is fixed. The second one is how the projectile parameters change in terms of the moving distance and the initial speed when the angle is fixed.

After considering the learning goals and the age of the target learners, the Angry Birds game is exploited to design an elementary gamification activity. Based on embodied cognition, education computer games can be implemented with a role-playing feature and the players can link the gaming experience with their daily lives (Lankoski & Järvelä, 2012). The gaming events and operations in the Angry Birds game are consistent with the learners' daily experiences and the knowledge behind the game regards fundamental projectile motion of physics.

Based on the perspective of embodied cognition, this study utilizes technologies of natural user interface to make learners be able to interact with the learning system through their body movements. The Angry Birds game is adopted to convey the abstract concept of fundamental projectile motion with learners' body-moving experience. In Figure 1 (a), the body-moving learning system consists of a Microsoft Kinect sensor, a laptop, and a big display. The Microsoft Kinect sensor was used to build the learning environment capable of sensing learners' movements. The learning system was developed in C# and executed with the Angry Birds PC game on the laptop (Figure 1 (b)). The external display is to provide learners a big visual area for watching the game details because the learners have to stand in front of the sensor about 2~3 meters and the laptop screen is too small.

Three gestures were designed for playing the game to enable learners to simulate the process of projectile motion. First one is that learners swing their right hand at different speed to control the projectile initial speed. Another one is that learners raise their left hand at different height to adjust the projectile angle. The last one is that learners raise both hands to confirm the adjustments regarding projectile initial speed and projectile angle, and then an angry bird is launched to hit targets. The top area of the system screenshot provides learners operational guides with pictures and text to prompt related functionalities for game playing. When learners move their hands, this area instantly present every position changes of their hand skeletons. The bottom area is the game area of the Angry Birds.

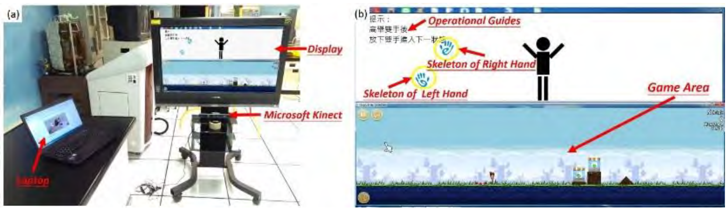

Figure 1. The body-moving learning's (a) environment setup; (b) system screenshot.

The finger-touching learning system is the Angry Birds game which runs on a FIC Tycoon 10.1-inch multimedia tablet PC. All operations are finished by finger-touching. In this case, learners play the game according the two learning goals. Compared to the body-moving learning, the finger-touching learning barely provides learners external perception related to the abstract concept of the learning content (Figure 2).

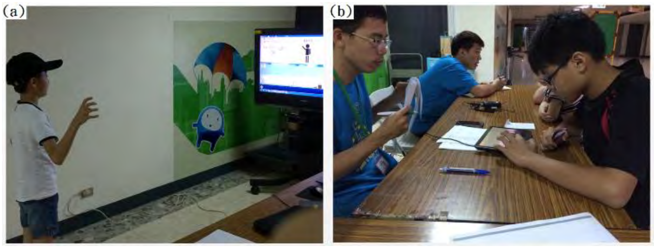

Figure 2. Learners in (a) body-moving learning; (b) finger-touching learning.

3 Method

This study applied technologies of natural user interface into elementary gamification activities for learning fundamental projectile motion. In order to evaluate learners' performance, an experiment was conducted including the body-moving and finger-touching learning groups. Krathwohl (2002) proposed the structure of the knowledge dimension of the Revised Bloom's Taxonomy including factual knowledge, concept knowledge, procedure knowledge, and metacognition knowledge. Factual knowledge regards the terminology of learning content that learners have to know. Procedure knowledge concerns that learners know how to apply what they have learned such as methods and skill. In body-moving learning group, learners can control the projectile initial speed by swing their hands at different speed. When they want to have a high projectile initial speed, they need to swing their hand quickly. On the other hand, learners in the finger-touching learning group just move their finger to control the projectile initial speed which is only related to the finger position, not to the speed. Therefore, hypothesis 1 is proposed as "*In fundamental projectile motion learning, the body-moving learning group has higher scores on the factual knowledge test than the finger-touching learning group*".

During the learning period, learners in the body-moving learning group can interact with the game objects in the learning system through their body movements. But learners in the finger-touching learning group can only interact with the game objects by moving their finger to different positions and touching the screen for confirmation. The body-moving learning group has external perception for knowledge construction than the finger-touching learning group. The body-moving learning group provides learners a learning context capable of interacting with the game objects and adjusting corresponding parameters through their body movements. Although learners in the finger-touching learning group can also interact with the game objects and adjust related parameters, the connection between knowledge and motor skill is not strong enough. Thus, hypothesis 2 is proposed as "*In fundamental projectile motion learning, the body-moving learning group has higher scores on the procedural knowledge test in terms of projectile initial speed, angle, and motor skill than the finger-touching learning group*".

A total of 60 elementary school students from grades four to six were recruited to participate in this experiment at National Science and Technology Museum, Taiwan. 30 of the participants are male. The average age is 10.82 with 0.93 standard deviation. Participations were randomly and equally divided into the body-moving learning group and the finger-touching learning group followed by the same instruction of fundamental projectile motion. After the experiment, every participations can get a gift as rewards.

The design of the tests of factual knowledge and procedural knowledge is based on the definitions of the structure of the knowledge dimension (Krathwohl, 2002). Factual knowledge was assessed by selecting related terms from eight keywords including sunshine, parabola, force, angle, speed, temperature, water, and weather. After the experiment, the participants have to answer what the keywords related to the learning of fundamental projectile motion.

The test of procedural knowledge includes the projectile methods and the motor skill to project an object to correct places. The projectile methods were assessed by a projectile motion simulation program from PhET (http://phet.colorado.edu) including projectile angle and projectile initial speed. The simulation program has been widely used in the educational field. The participants were asked to finish two parts. First part is to fix projectile angle, and the participations only change the value of projectile initial speed to make the object hit the target. Second part is to fix projectile initial speed, and the participants only change the value of projectile angle to make the object hit the target. The total scores for each part is 10. Each learner in each part is allowed to have ten tries. When the learner fails a try, the scores will be deducted one point and the worst case is zero. A screenshot of this test is shown in Figure 3(a).

In the evaluation of the motor skill, learners have to throw a ball and sees if they can hit the scoring area in real world (Figure 3(b)). Firstly, participations should stand on the starting point. The throwing gesture in the motor skill is requested to be identical with that in the gamification activity. This test has two part including near-end and far-end. The total score in each part is three points. A learner has two opportunities in each part for practicing and three tries for counting scores. In each part, there are five blocks, one for ten points, two for five points, and two for one point. If a learner throws the ball out of the five blocks, the learner only gets one point.

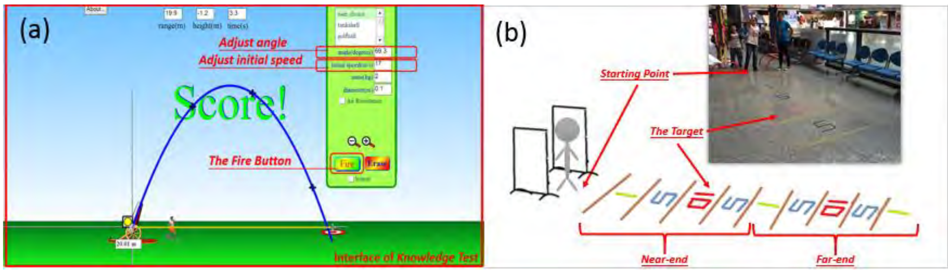

Figure 3. Procedural knowledge test (a) projectile initial speed and angle; (b) motor skill

Before the experiment, an instructor introduced the entire process to participants. At the beginning, a pre-test of procedural knowledge was conducted for five minutes. Then participants were randomly and equally divided into body-moving learning group and finger-touching learning group. Then, the learners in each group received corresponding instruction regarding the knowledge of fundamental projectile motion and the operation of the learning system for five minutes. In terms of learning system operation, each participant watched a demonstration of an instructor and had two opportunities to practice in person. Then, each participant started to perform the gamification activity for seven minutes. After the learning activity, a post-test of procedural knowledge was conducted for five minutes and the factual knowledge test was performed in two minutes. The pre-test and post-test of procedural knowledge is mostly the same only with different default parameters to avoid memorization effect. At the end of experiment, participants were requested to fill out a questionnaire in two minutes for collecting demographic data.

4 Results and Discussion

The descriptive statistic of the factual knowledge shows that most of participants chosen four keywords, namely parabola, force, angle, and speed. For hypothesis 1, an independent-sample t-test was used to test the difference between the body-moving learning group and the finger-touching learning group. This result shows that the body-moving learning group has better outcome in terms of speed than the finger-touching learning group (t = 2.918, p < 0.01). No significant difference was found in the other seven keywords. The participants in the body-moving learning group have to swing their hand to control the projectile initial speed. The projectile initial speed reflects on how quick the learners swing their hand. Therefore, the learners can have a strong impression on speed. On the other hand, the learners in the finger-touching learning group just move their finger on the screen of the tablet PC and no related external clues can make their thinking associated with speed.

For hypothesis 2, this study used independent-sample t-test to test the difference between the body-moving learning group and the finger-touching learning group. No significant differences were found in the result of the pre-test which suggests that all participants in this experiment do not have significant differences of procedural knowledge in terms of projectile angle, projectile initial speed, and motor skill. The result of the post-test is shows in Table 1. The body-moving learning group has significantly higher scores of projectile angle than the finger-touching learning group (t = 2.189, p < 0.05). No significant differences were found in terms of the projectile initial speed and the motor skill.

Table 1: Independent-sample t-test result of procedural knowledge.

Type	Body-moving learning group (N=30)	Finger-touching learning group (N=30)	t (p)
	Mean (SD)	Mean (SD)	
Projectile angle	7.33 (1.688)	6.37 (1.732)	2.189* (0.033)
Projectile initial speed	7.37 (1.629)	7.73 (1.413)	-0.931 (0.356)
Motor skill	44.80 (9.925)	44.63 (7.712)	0.073 (0.942)

* $p < 0.05$

The result of procedural knowledge does not fully consist with the hypothesis 2. Two probable explanations are addressed in this study. The first one is that the design of the Angry Birds game which only emphasizes the adjustment of the projectile angle, not the adjustment of both projectile angle and projectile initial speed. The body-moving learning system can reflect the speed of swing a hand on the projectile initial speed in the game. By reviewing the video recording, most of the learners in the body-moving learning group would rather swing their hand at high speed than at low speed. The same situation also occurred in the finger-touching learning group. Therefore, it may affect the result of the procedural knowledge. The other explanation is that the elementary school student is too young to have an adult-like mature cognitive development. The embodiment-based design can facilitate learners to link body movements with the game objects and parameters. However, the young learners have difficulty to transform such experience from what they learned into real practices and applications because the gamification activity was performed in a third-person view. The motor skill was assessed in a first-person view. Thus, the young learners could not deal with the change of viewpoints well, and the outcome of motor skill is likely to be interfered.

5 Conclusion

This study exploits the Angry Birds game to provide elementary students gamification activities and improve their learning of fundamental projectile motion through an embodied approach. According to the results, the body-moving learning group outperformed the finger-touching learning group on speed in factual knowledge test and projectile angle in procedure knowledge test. These results have already shed light on the potential of gamification activities to learn factual knowledge and procedure knowledge of subjects. Although not all test items are significant, the learners in the body-moving learning group certainly obtain improvements on speed in factual knowledge and projectile angle in procedure knowledge. This study designs the gamification activities which can be accomplished in just seven minutes. Short period gamification activities are fairly appropriate for learning in field trips such as a part of educational exercises in a museum. Because the cognitive development of young learners is still in progress, the gaming experience can motivate them and learning by doing is also one good practice for digital game enhanced learning. One research limitation in this study is the fixed third-person viewpoint of playing the game because the off-the-shelf commercial game was used. Although the body-moving learning can link body movements with the game objects and parameters, the learning outcomes would be affected by the extent of learners' cognitive development. Instructors and researchers have to take care of the issue of viewpoint changes for young learners when designing an embodiment-based learning system.

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