Liu, C.-C. et al. (Eds.) (2014). Proceedings of the 22nd International Conference on Computers in Education. Japan: Asia-Pacific Society for Computers in Education

The Development and Evaluation of an Educational Game- *Shimmer*© with Computer Visualization for Optics Learning

Huei-Tse HOU[a*], Shu-Ming WANG[b], Hsin-Hung YU[a] & Shie-He LIU[a]
[a]*Graduate Institute of Applied Science and Technology, National Taiwan University of Science and Technology, Taiwan*
[b]*Department of Information Management, Chinese Culture University, Taiwan*
[*]hthou@mail.ntust.edu.tw

Abstract: Learning physics involves the reasoning of abstract, dynamic, and complex that cannot be mapped to learners' daily experience or observed with naked eyes. with the advancement of computer technologies, nowadays, computer technologies, such as simulation and scientific visualization, are able to depict the scientific phenomena with vivid visualization and rich interaction. Recently, in addition to provide simulation and scientific visualization, many educational games were developed to support learning of various subjects in order to promote the level of students' engagement in learning. Educational games with clear goals, immediate feedback, and adequate scaffolding were considered as a powerful means of improving students' learning motivation and subsequent learning performance. Though game-based learning has been a trend in recent years, researchers suggested that research on the application of game-based learning to STEM is still relatively limited. To fill the literature gap, this study developed a game – *Shimmer*© to support the learning of optical concepts. This study conducted an experiment with 50 seventh-grade students. An analysis of pretest and posttest was conducted to examine the effects of the game on learning. In addition, the participants' evaluation of game and their gaming experience were assessed via using flow constructs. Furthermore, individual differences were addressed as well. Results showed that the participants generally better capture the concepts of light reflection and refraction in visual way. Besides, further analyses of individual differences indicated that boys and girls as well as students with high and low prior knowledge evaluated the game differently. Implications for the results of this study are to be used as guidance for subsequent game development and design of instructional strategies.

Keywords: Game-based learning, STEM, Optics, flow

1. Introduction

Scientific learning involves numerous abstract concepts, which cannot be directly observed or mapped to learners' day-to-day experience (Anderson & Barnett, 2013). For example, the concepts of optics and wave cannot be directly observed without adequate instruments (Hamam, 2003). When learning these concepts, it would be difficult for learners to capture and integrate the abstract, complex, and discrete ideas to form correct conception of a particular phenomenon. Sometimes, learners would even form misconceptions if improperly guided (Anderson & Barnett, 2013; Masson, Bub, & Lalonde, 2011). Nonetheless, with the advancement of computer technologies, nowadays, these abstract, dynamic, and complex phenomena can be depicted by using computer simulation or scientific visualization techniques to improve learners' understanding (Chen, Pan, Sung, & Chang, 2013; Van Dam, Forsberg, Laidlaw, LaViola, & Simpson, 2000). Previous studies have adopted technologies, e.g., virtual reality or interactive computer simulation, to support the teaching of abstract concepts, such as electrostatics (Anderson & Barnett, 2013), object motion (Masson et al., 2011), and optics (Mzoughi, Herring, Foley, Morris, & Gilbert, 2007).

As to learning optics, it could be difficult for learners to catch the concepts of optics, as it is invisible to naked eyes (Mzoughi et al., 2007; Van Dam et al., 2000). Though the lab experiment could be helpful to improve students' understanding, it could be complex and costly for setting up a lab experiment as the class is getting larger. This situation makes computer visualization be an ideal tool to support the learning of the concepts of optics (Mzoughi et al., 2007; Van Dam et al., 2000). In response to this issue, Mzoughi et al. (2007) developed a 3D interactive computer graphics system – WebTOP for teaching and learning optics. WebTOP adopted the features of visual simulation to illustrate the optical concepts, such as reflection and refraction, lasers and scattering etc., allowing that learners better understand these phenomena. The system can support both classroom use and self-guided study and received generally positive affirmation from both educators and students. However, one general constraint for computer simulation is that users might be lack of motivation to engage in the repetitive process or they could easily get bored. This situation could diminish the educational benefits of using computer simulation for teaching and learning.

To improve users' motivation and level of engagement in learning, employing an educational game to support teaching and learning has been a trend in educational practices nowadays (Anderson & Barnett, 2013). An educational game adopts game mechanism in addition to computer simulation and visualization. Like computer simulation, computer games allow players to interact with the content and receive immediate feedback, which can be used to adjust their action or conception accordingly. Well-designed computer games provide clear goals with different levels of challenge that require players to explore the means to achieve. Rewards are provided as players reached the goals afterward. This process provokes intriguing experience that promotes players' motivation to and engagement in gaming (Mayo, 2009; Prensky, 2001; Young et al., 2012). In the educational context, games can be adapted to individual learners' pace and scaffold them through the learning process. For example, complex learning tasks can be decomposed to smaller tasks at the beginning of a game. As the level of challenge gradually gets easier, players would have opportunity to practice simple tasks several times before they deal with more complex learning tasks (Mayo, 2009). Through the repetitive practice, learners are expected to attain the mastery of particular cognitive skills (Prensky, 2001).

Witnessing the surging popularity of games and advantages of adopting games for learning, many educational games have been developed in recent years. However, there is relatively limited research on game-based STEM (science, technology, engineering, and mathematics) in the past decade (Young et al., 2012). In order to fill the literature gap, this study developed an educational game – *Shimmer©* to support the learning of optics and conducted a preliminary study to improve our knowledge about adopting game to support learning. The description of *Shimmer©* is presented in Research Method section.

To explore why and how people play games, previous game-related studies have used the idea of flow from psychology literature to assess the optimal gaming experience (e.g. (Barzilai & Blau, 2014; Hsu & Lu, 2004; Kiili, 2006). Flow experience refers to the perception of being totally absorbed to the activity in which people engaged. People would feel a sense of enjoyment, distortion of time, loss of self-conscious, and intrinsically motivated when they were in flow state (Csikszentmihalyi, 1994). Flow is therefore adopted as an important indicator of intriguing experience when playing games. Nonetheless, there are prerequisite conditions for the occurrence of flow experience. One essential element of flow is that the level of challenge has to match the player's level of skills. Otherwise, the player could get anxious when the level of challenge is significantly higher; on the contrary, the player would get bored when the level of skills is significantly higher. Moreover, people need to feel in control of what they are doing and feel that they are pursuing a clear goal (Kiili, 2006). This study adopted flow experience to assess the participants' evaluation of *Shimmer©* and their gaming experience. Besides, the effects of individual differences have been regarded as influential factors in educational research (Li, Cheng, & Liu, 2013; Yukselturk & Bulut, 2009). This study further looked into the plausible effects of individual differences on participants' learning outcomes, evaluation of game, and gaming experiences. Concluding from the above, the purposes of this preliminary study are summarized as follows:

1. To examine the difference of learning outcomes before and after playing the game - *Shimmer©* .
2. To explore the plausible differences of game evaluation and gaming experience of *Shimmer©* for students with different gender.

3. To explore the plausible differences of game evaluation and gaming experience of *Shimmer©* for students with different level of prior knowledge.

The initial findings of this preliminary study could help us better understand the effectiveness of *Shimmer©*, which visualizes the abstract and dynamic concepts of optics. These findings would also serve as a guideline for improving the future version of *Shimmer©*. Moreover, based upon the findings, suggestions for incorporating scientific visualization with game-based learning were purposed. The following sections are to delineate the introduction of game and the experimental design.

2. Research method

2.1 Procedure and Participants

This educational game used in this study was a 3D simulation game - *Shimmer©*, which was developed via Unity3D game engine. In the game, the player needs to protect civilians in a small village from the invaders. In each stage, there were a laser cannon, several plane mirrors and lenses, and one invader sat on a floating island as shown in figure 1. By clicking on the mirrors and lenses, players could calibrate their angle and location. Once the players finished the calibration, they could click on the laser cannon to launch a laser and check how it traveled. The goal of the game was to correctly set up the angle and location of the lenses so that the laser could shoot the invader. At current version of the game, players were allowed for unlimited trials. The concepts of optics introduced in the current version of *Shimmer©* are about reflection and refraction. At the beginning stages, there were plane mirrors only. Players could simply calibrate the angle of plane mirrors to achieve the goal. These stages were designed to help players to be acquainted with the game and learn the basic ideas of light reflection. At the further stages, convex and concave lenses as well as obstacles sited on the path of laser transmission were added, which would gradually increase the difficulty level of the game (as shown in figure 2). There were 15 levels of game challenges in current version of *Shimmer©*. A non-player character (NPC) - the Sage was created to provide relevant knowledge of light refraction. Players could click on the Sage to read the needed information at any time during the game. Screenshot of the provided information is shown in figure 3.

Figure 1: Game screenshot of the beginning stage.

Figure 2: Game screenshot of the advanced stage.

Figure 3: In-game optics knowledge guidance

The participants of this study were 50 seventh-grade students in a junior high school in northern Taiwan, including 28 males and 22 females. The experiment was conducted in a PC classroom. Before the experiment, students were asked to fill a pretest to assess their prior knowledge of light fraction. Students have to complete the pretest in seven minutes. The pretest was followed by a five-minute introduction of the game. Afterward, students were to freely play the game for 20 minutes. Finally, students were asked to fill a posttest as well as a flow instrument. The total time of the experiment was around 45 minutes.

2.2 Instruments

This study developed a test, which was used in the pretest and posttest session. The test included 8 multiple-choice questions, which were primarily adapted from the textbook, and 4 questions that asked students to draw the direction of light transmitted through the lenses. The example of drawing question is as shown as figure 4. In this example, the arrow showed the direction of the light. Participants were asked to draw the travel path of the light. Students were given one point for each correct answer.

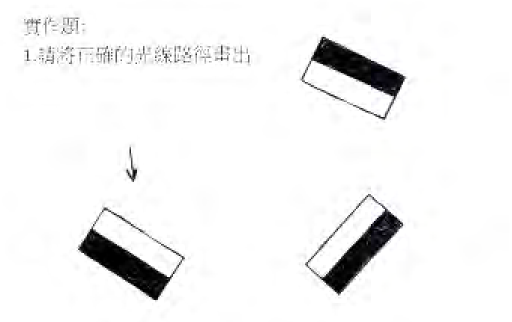

Figure 4: Example of a drawing question

The flow instrument was adapted from Kiili (2006). 22 items were used to assess two major components of the flow construct. The first component is flow antecedents, which represents players' evaluation of the game in terms of the level of challenge, goal, feedback, control, and playability. The second component is flow experience, which reflects players' perception of concentration, time distortion, autotelic experience, and loss of self-consciousness when playing game. The flow instrument was measured using five-point Likert scale from 1 (strongly disagree) to 5 (strongly agree).

3. Data Analysis and Results

3.1 Learning outcomes

SPSS 20.0 was used to analyze the collected data. Table 1 summarized the participants' scores in pretest and posttest as well as the results of mean difference test. As shown in Table 1, overall, there was a significant difference between the pretest and posttest. However, further analysis revealed that there was no difference in the scores of multiple-choice. Nonetheless, after playing the game, students' performance of drawing question was significantly higher than before ($t = -5.14$, $p < 0.001$).

Table 1: Summary of students' performance in pretest and posttest.

Type of questions	Pretest (n=50)		Posttest (n=50)		t-statistics	p-value
	Mean	S.D.	Mean	S.D.		
Multiple-choice	4.38	1.92	4.46	2.11	-0.29	0.773
Drawing	0.46	0.68	1.18	1.02	-5.14	.000
Overall	4.84	2.24	5.64	2.58	-2.53	0.015

For the flow construct, the Cronbach's α of flow instrument was 0.971, suggesting high reliability (Nunnally, 1978). The participants generally possess positive evaluation of the game. Specifically speaking, the participants evaluated *Shimmer©* as challenging (mean = 3.64), with clear goals (mean = 4.10), providing prompt feedback (mean = 3.71), controllable (mean = 3.64), and playable (mean = 3.52). Meanwhile, all the means of sub-constructs of flow experience exceeded 3.5, suggesting that the participants generally have positive flow experience while playing game.

3.2 Individual differences

Individual difference was considered as an important factor in educational research (Price, 2006; Yukselturk & Bulut, 2009). In the context of gaming, the stereotypical view of males is that they might be more interested and engaged in playing video game than females (Chumbley & Griffiths, 2006; Yee, 2006). In addition, when playing game, males and females might behave differently. For example, girls would be more focus on causal interaction with other players, whereas boys would tend to focus on game-related conversation (Young et al., 2012). These differences would affect their evaluation of an educational game. In this regard, this study conducted a further analysis to explore the potential differences between boys and girls in evaluation of *Shimmer©* in terms of flow antecedents. The results showed that boys, in contrast to girls, showed higher evaluation of game challenge ($t = 2.96$, $p < 0.05$), feedback ($t = 3.62$, $p < 0.01$), and playability ($t = 2.72$, $p < 0.05$). However, there were no differences observed in their evaluation of game goal ($t = 1.69$, $p > 0.05$) and control ($t = 1.855$, $p > 0.05$). Regarding the flow experiences, boys reported higher degree of flow experience in concentration ($t = 2.22$, $p < 0.05$), autotelic experience ($t = 2.78$, $p < 0.05$), and loss of self-consciousness ($t = 2.51$, $p < 0.05$). Nonetheless, the difference in time distortion was not observed ($t = 1.71$, $p > 0.05$).

To further explore the plausible differences in students' flow experience, this study conduct a test for difference between the means of students with high and low prior knowledge. Based on their scores in the pretest of this study, students whose scores were above the top 27% were categorized into high prior knowledge group (N=14), whereas those who below the bottom 27% were categorized into low prior knowledge group (N=14). The results indicted students with high prior knowledge reported higher degree of experiencing time distortion than those with low prior knowledge ($t = 2.28$, $p < 0.05$). However, there were no differences observed in other flow dimensions. The interpretation and discussion of these results are to be presented in the following section.

4. Conclusion and subsequent research

With the technology advancement, modern computer games are able to simulate the scientific phenomena and create an immersing environment that follows the natural laws of physics for educational purposes (Anderson & Barnett, 2013). With this affordance, computer games have been used to support learning of various subjects. In particular, computer games are commonly used to support the learning of abstract concepts or complex procedures (Kebritchi & Hirumi, 2008). This study developed an educational game – *Shimmer©* to support the learning of optical concepts. The initial findings suggested that *Shimmer©* was helpful to improve students' conceptions of reflection and refraction, particularly in visual depiction. Participants generally reported positive flow experience, which was considered as an essential component of intriguing gaming experience, when playing *Shimmer©* . The discussion and implications of findings are delineated as below.

First of all, the game – *Shimmer©* helped the participants better capture the ideas of reflection and refraction. In particular, after playing the game, the participants were more able to correctly draw the path that light travels among mirrors, convex and concave lenses than before. *Shimmer©* allowed players to form their hypotheses of how light travels and then set up the angle and location of lenses to freely test and alter their hypotheses for unlimited times. This process could enhance students' autonomy in learning, which could promote their learning motivation and thus achieve better learning outcomes (Ryan, Rigby, & Przybylski, 2006; Vogel et al., 2006). Nonetheless, there was no significant difference in multiple-choice questions between the pretest and posttest. One plausible explanation may result from the form of problem representation in the game. In *Shimmer©* , students need to calibrate the lenses in order to make the light hit the target. In the process, they were able to observe the results of light transmitted through lenses of different angles and locations. Therefore, they would form the conceptions of reflection and refraction in visual way. *Shimmer©* didn't require players to memorize factual knowledge to achieve the game goal. In other words, students needn't to answer the traditional form of test when playing game. Thus, their performance on multiple-choice questions could be limited. Similar notions have been proposed by previous research. Masson et al. (2011) suggested that the engagement benefits of games are suited for training particular cognitive skills. Nonetheless, this immersing environment and repetitive process might make learners be less accomplished with regard to traditional test performance (Young et al., 2012).

Secondly, analysis of gender difference showed that boys tend to have higher evaluation in most dimensions of flow antecedents. As boys were regarded as typical gamers, they might be more able to adapt to game control than girls are (Chumbley & Griffiths, 2006; Yee, 2006). However, lacking of control could impede players from immersing in the game play, which in turn diminishes the level of engagement and the effects of game-based learning (Hou, Wang, & Tsai, 2013; Scoresby & Shelton, 2011). Nonetheless, in this study, there were no differences in boys and girls' perceptions of game goal and controllability. This may result from the game goal of *Shimmer©* , whose goal was to shoot the invader with a laser cannon, which was simple and clear enough for both boy and girl participants. Moreover, the participants only need to click on the lenses to calibrate the angle and location of them. No complicated operations were required. Regarding the flow experiences, boys seemed being more absorbed into the game as they generally reported higher degree of flow experience in concentration, autotelic experience, and loss of self-consciousness. However, the difference in sense of time distortion between boys and girls was not observed. This non-significant result could be attributed to the limited time of the game session (20 minutes) and a small sample size. Subsequent research is suggested to extend the game session and conduct a larger scale of experimentation to further investigate the gender differences in flow experience.

Lastly, regarding to individual differences, though the participants with high and low prior knowledge generally reported positive flow experience (i. e. mean of all sub-dimensions exceeded 3.5), results indicated that participants with higher prior knowledge tend to have significantly higher sense of time distortion. It seemed that they were more engaged in playing game. This finding was probably because students with higher prior knowledge were able to capture the ideas in game. Thus, they would be more focused on solving the problem than those with lower prior knowledge were. This finding also emphasized the importance of the match between the level of challenge in game and the skills of players, which is a prerequisite condition for the occurrence of flow experience (Csikszentmihalyi, 1994). Thus, it is suggested that the design of an educational game should consider the prior knowledge of learners in order to induce the optimal gaming experience while playing (Barzilai & Blau, 2014; Kiili, 2006).

5. Research Limitations and subsequent study

As a preliminary study, this study was limited in the time of game session and sample size; thus, these initial findings should be interpreted with cautions. First, the short game session could be a limitation for the students to properly evaluate the game and to have flow experience. In this manner, the longer game sessions are needed to further investigate the effects when using the game – *Shimmer©* to support the learning optical concepts. Secondly, an elaborated experimental design with more participants, which involves the control group provided for other instructional practice such as simulation, would help us better compare the effectiveness of game-based learning with that of traditional practice. Lastly, the advantages of game-based learning are not merely to promote learners' engagement. Mayo (2009) suggested using in-game assessment to track the sequences of players' behaviors, such as the number of attempts to solve a problem, the timing of seeking online help, or interaction among players. This approach can help instructors to further look into the learning process and provide feedback for game developers to improve the game design. In this manner, the subsequent research is suggested to employ sequential analysis to explore players' gaming patterns, which would help us better understand how players interact with the game and improve the future version of *Shimmer©* .

Acknowledgements

This research was supported by the projects from the National Science Council, Republic of China, under contract number MOST-102-2511-S-011-001-MY3, MOST-100-2628-S-011-001-MY4, MOST-103-2511-S-034-001 and NSC-102-2511-S-034-001.

References

Anderson, J., & Barnett, M. (2013). Learning physics with digital game simulations in middle school science. *Journal of Science Education and Technology, 22*(6), 914-926

Barzilai, S., & Blau, I. (2014). Scaffolding game-based learning: Impact on learning achievements, perceived learning, and game experiences. *Computers & Education, 70*(0), 65-79

Chen, Y.-L., Pan, P.-R., Sung, Y.-T., & Chang, K.-E. (2013). Correcting Misconceptions on Electronics: Effects of a simulation-based learning environment backed by a conceptual change model. *Educational Technology & Society, 16*(2), 212-227.

Chumbley, J., & Griffiths, M. (2006). Affect and the computer game player: The effect of gender, personality, and game reinforcement structure on affective responses to computer game-play. *CyberPsychology & Behavior, 9*(3), 308-316.

Csikszentmihalyi, M. (1994). *Flow: The Psychology of Optimal Experience.* New York, NY: Simon & Schuster Audio.

Hamam, H. (2003). An interactive web-based tool for teaching optics and vision. *Optics and Photonics News, 14*(8), 30-34.

Hou, H.-T., Wang, S.-M., & Tsai, D.-S. (2013). *The development and evaluation of a 3D simulation game for chemistry learning: exploration of learners' flow, acceptance, and sense of directions*. Paper presented at the The 21st International Conference on Computers in Education (ICCE 2013), Bali, Indonesia.

Hsu, C.-L., & Lu, H.-P. (2004). Why do people play on-line games? An extended TAM with social influences and flow experience. *Information & Management, 41*(7), 853-868.

Kebritchi, M., & Hirumi, A. C. (2008). Examining the pedagogical foundations of modern educational computer games. *Computers & Education, 51*(4), 1729-1743

Kiili, K. (2006). Evaluations of an experiential gaming model. *Human Technology: An Interdisciplinary Journal on Humans in ICT Environment, 2*(2), 187-201.

Li, Z.-Z., Cheng, Y.-B., & Liu, C.-C. (2013). A constructionism framework for designing game-like learning systems: Its effect on different learners. *British Journal of Educational Technology, 44*(2), 208-224.

Masson, M. E. J., Bub, D. N., & Lalonde, C. E. (2011). Video-game training and naïve reasoning about object motion. *Applied Cognitive Psychology, 25*(1), 166-173.

Mayo, M. J. (2009). Video Games: A route to large-scale STEM education? *Science, 323*(5910), 79-82.

Mzoughi, T., Herring, S. D., Foley, J. T., Morris, M. J., & Gilbert, P. J. (2007). WebTOP: A 3D interactive system for teaching and learning optics. *Computers & Education, 49*(1), 110-129.

Nunnally, J. C. (1978). *Psychometric Theory* (2nd ed.). New York: McGraw-Hill.

Prensky, M. (2001). *Digital Game-based Learning*. New York: McGraw-Hill.

Price, L. (2006). Gender differences and similarities in online courses: Challenging stereotypical views of women. *Journal of Computer Assisted Learning, 22*(5), 349-359.

Ryan, R. M., Rigby, C. S., & Przybylski, A. (2006). The motivational pull of video games: A self-determination theory approach. *Motivation and emotion, 30*(4), 344-360.

Scoresby, J., & Shelton, B. (2011). Visual perspectives within educational computer games: Effects on presence and flow within virtual immersive learning environments. *Instructional Science, 39*(3), 227-254.

Van Dam, A., Forsberg, A., Laidlaw, D. H., LaViola, J. J., & Simpson, R. M. (2000). Immersive VR for scientific visualization: a progress report. *Computer Graphics and Applications, IEEE, 20*(6), 26-52.

Vogel, J. J., Vogel, D. S., Cannon-Bowers, J., Bowers, C. A., Muse, K., & Wright, M. (2006). Computer gaming and interactive simulations for learning: A meta-analysis. *Journal of educational computing research, 34*(3), 229-243.

Yee, N. (2006). Motivations for play in online games. *CyberPsychology & Behavior, 9*(6), 772-775.

Young, M. F., Slota, S., Cutter, A. B., Jalette, G., Mullin, G., Lai, B., . . . Yukhymenko, M. (2012). Our Princess Is in Another Castle: A review of trends in serious gaming for education. *Review of Educational Research, 82*(1), 61-89.

Yukselturk, E., & Bulut, S. (2009). Gender differences in self-regulated online learning environment. *Journal of Educational Technology & Society, 12*(3), 12-22.