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The Development and Evaluation of a 3D Simulation Game for Chemistry Learning: Exploration of Learners' Flow, Acceptance, and Sense of Directions

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Abstract: Among various educational technology, computer game could be one of the most popular applications in recent years. Nowadays, computer games can provide a 3-dimensional (3D) immersive virtual world to increase learners' perception of presence and simulate the real world objects to support learning. The immersive learning environment, visualization of abstract concepts, and high level of interaction could benefit learners' engagement and learning outcomes. Despite previous studies have investigated the influential factors of educational gaming experience, however, in the 3D virtual world, learners might need other ability, such as sense of directions (SOD), for them to be acquainted with the virtual environment and thus can learn better. This preliminary study developed a 3D educational game to support chemistry learning. In the game, learners were to explore the virtual world to collect components for they can assemble a charcoal battery to achieve the game goal. A case study of 20 participants was conducted to assess the effectiveness of the game. Results suggested that participants gained better knowledge after playing the game. Meanwhile, participants with better SOD can more clearly capture the game goals and feel in control in the game, suggesting they were immersing in the game. Moreover, they also evaluate the game as useful to support their learning. A test of gender difference found that male and female evaluated the game in different way. Implications for the results of this study are to be used as guidance for subsequent game development and design of instructional strategies.

Keywords: Sense of Directions, TAM, Flow, educational game

1. Introduction

With the proliferation of technology, incorporating technology to support learning has been a common practice in education. Among modern technologies, computer game could be the one of the technologies that youth students are most familiar with. In this regard, previous research has focused on how to utilize the characteristics of computer games to support learning (e.g. de Freitas et al., 2012; Scoresby & Shelton, 2011; Wu, Chiou, Kao, Alex Hu, & Huang, 2012).

Previous studies suggested that educational games with adequate design and instructional support are able to promote students' engaging in learning and thus better learning outcomes (Chang, Wu, Weng, & Sung, 2012; Huang, 2011; Kiili, 2005; Wouters & van Oostendorp, 2013). However, Kiili(2006) pointed out that most of the educational games were primarily support factual information learning. The interaction between the game and the learner is similar to learning with exercise books by answering the questions it provided. Kiili(2005) stressed the experiential aspects of gaming, such as immediate feedback, goals, and challenges, that could facilitate learner's engaging in learning.

Moreover, computer games with first person perspective could increase learners' perception of presence in the virtual world, which is regarded as an important component in an immersive learning environment (Scoresby & Shelton, 2011). With the advancement of graphical computing power, nowadays, 3-dimensional (3D) computer games can present a virtual environment that allows players to interact with the objects of the game in first person perspective. 3D computer games were considered as an effective educational tool and preferred by students among various types of computer game (Amory, Naicker, Vincent, & Adams, 1999). In 3D computer games, players need to navigate the environment to achieve the goals of the game, such as arriving at specific spot or collecting objects scattered in different spaces. In this manner, players might need better sense of directions to complete the goals and challenges in the game. Otherwise, players might feel lost in the game world and demotivated to play the game. Despite few previous studies have investigated the effectiveness of using 3D educational games to support learning, with the best knowledge of the authors, none of them has researched the effects of players' sense of directions to the learning experience.

The interactivity and immersion of computer games can also be used as simulation for learning activities that involve abstract concepts or complicate procedures. For example, Liu, Cheng, and Huang (2011) employed simulation games to support computer programing learning and found that students using simulation game has better intrinsic motivation and learning experience, which thus enhanced their problem-solving skills. Pasin and Giroux (2011) used simulation game to support operation management learning, which seeks to develop decision making ability in complex situation. Their results showed that students developed more advanced decision making ability with the support of simulation game. Thus, simulation game might be an ideal tool for particular subjects, such as chemistry in this study. Learning chemistry involves abstract concepts and laboratory activities that can be dangerous and complex. Computer simulation game can be helpful in visualizing the abstract concepts and improve students' comprehension of the procedures and interest of laboratory activities before doing actual experiment (Rutten, van Joolingen, & van der Veen, 2012).

Despite previous studies have addressed the important factors of level of players' engagement with game, such as flow experience (i.e. Chang et al., 2012) or technology beliefs (i.e. Hsu & Lu, 2004), relatively little has been discussed in the context of educational game. Moreover, most of educational games were plain digital exercise book-like 2D game. As mentioned above, Amory et al. (1999) pointed out that 3D adventure games are preferred by students with its immersive environment and sense of presence in the game scene. However, when exploring the 3D virtual scene, better sense of directions (SOD) could be helpful for players to successfully locate themselves and game objects to achieve the game goal. Otherwise, players might be disoriented in the virtual world and thus feel bored with playing the game. In other words, SOD could be an influential factor that affecting players' engagement with and learning outcomes of 3D adventure-like educational games. However, to the authors' best knowledge, there is no research investigated the effects of SOD to the game experience and learning outcome. On the other hand, in traditional chemistry class, the procedures were lectured and allowed students to practice in a laboratory activity. However, the laboratory activities can be dangerous and incur extra cost if students are not familiar with the procedures. Computer simulation helps reducing the potential risk and improving students' motivation to and interest in engaging the laboratory activities (de Jong, 1991; Rutten et al., 2012). Moreover, combining the element of gaming and computer simulation could be an ideal solution to help students learn better and promote the level of engagement in learning. To address the aforementioned literature gap and utilizing the benefits of computer simulation game, this study developed a 3D adventure game to support the chemistry learning. The subject to learn is the procedure of assembling a charcoal battery. Introduction of the game is presented in the Research Method section.

Regarding gaming experience, flow could be the most mentioned experience when playing game. Flow experience refers to the perception of being total absorbed to the activity that people engaged (Scoresby & Shelton, 2011). When flow experience occurred, people may feel enjoyment, distorted sense of time, intensive control of the activity, and intrinsically motivated (Csikszentmihalyi, 1994). However, an important precondition of flow experience is the match of challenges of the activity and the actor's skill. When the challenge is greater than the actor's skill level, the actor could feel anxious. On the contrary, when the level of actor's skill level is higher than challenge, people might feel bored. Both situations prevent the actor to enter flow state (Csikszentmihalyi, 1994; Kiili, 2005). The flow experience of flow can be used as sign to assess players' engagement with the game. Moreover, besides the flow experience, to assess players' evaluation of the game, this study also adapted two constructs of the Technology Acceptance Model (TAM, Davis, 1989). Concluding from above, the purposes of this study are as listed as following:

1. To examine the difference of learning outcomes before and after playing the game in this study.
2. To explore the plausible differences of game evaluation and gaming experience for players with different level of SOD.
3. To explore the plausible differences of game evaluation and gaming experience for players of different gender.

Results of this preliminary study can be helpful in better understanding the role of the SOD in a 3D adventure game and to players' evaluation of the game to support chemistry learning. The introduction of game and the experiment design are to be detailed in the following section.

2. Research method

2.1 Participants and procedure

This educational game used in this study is in a Doom-like 3D adventure game. The goal of the game is to find the exit of a 3D virtual maze with monsters wandering around. The maze was divided to few connected areas and there are electronic gates between these areas. Players have to collect components of charcoal battery and assemble them into charcoal battery to produce the energy to open the electronic gates. Besides, the assembled charcoal battery also provides energy for the laser gun for players to defeat the monsters in the game. Players need to follow the correct sequence of procedure to assemble the charcoal battery. Players need to assemble the charcoal battery in correct sequence once they collected all the components. While playing the game, messages and indications were provided in order to support learners to advance further steps or notice important objects. Snapshots of the game scene are as shown in Figure 1 and Figure 2.

The participants of the study are 20 students of a university in northern Taiwan. Half of them are female (female=10; male=10). The average age of participants was 24.45. The experiment was conduct in a course – Introduction to Computer that the participants enrolled. The experiment was of three sessions. In the first session, one of the authors explained the procedure to assemble a charcoal battery to the participants. An interactive animation was used to illustrate the procedure. The second session is primarily to prepare students for the needed knowledge to play the game. The goal of game and how to control the game using mouse and keyboard were clearly presented in this session. Before students can play the game, a pretest was conduct to assess students' knowledge about assembling the charcoal battery as well as the sense of direction. In the third session, students were given 25 minutes to freely explore the game. Students were asked to play the game without discussing with their peers during this session. After the game session finished, a posttest, sense of directions, technology acceptance beliefs, and flow experience were assessed.

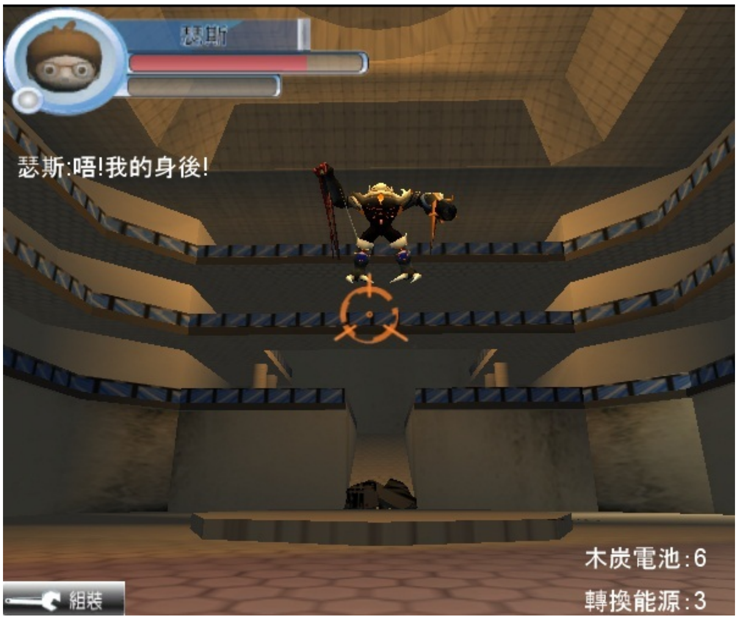

Figure 1: A snap shot of game scene.

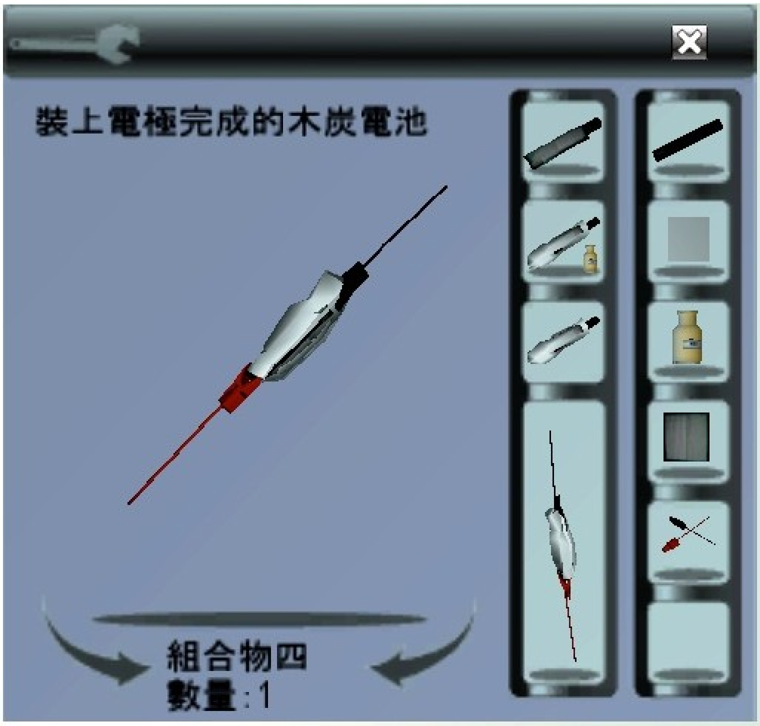

Figure 2: A snapshot of charcoal battery assembling game screen

2.2 Instruments

The instruments employed in this study were primarily adapted from previous validated scales. The wording has been slightly modified to fit the research context of this study. In specific, fifteen items of sense of directions were adapted from Hegarty, Richardson, Montello, Lovelace, and Subbiah (2002). Technology acceptance beliefs, i.e. perceived ease of use (PEU) and perceived usefulness (PU) were measured using the scales adapted from the Technology Acceptance Model (TAM) proposed by Davis (1989). Flow antecedents and flow experience were adapted from (Kiili, 2006). Kiili (2006) proposed four constructs as flow antecedents to assess players' evaluation of the game, namely the challenge, goal, feedback, control, and playability. The flow experience was represented by players' perception of concentration, time distortion, autotelic experience, and loss of self-consciousness. There are 22 items in total to assess the flow antecedents and experience. All the above mentioned scales were assessed using five-point Likert-scale from 1 (strongly disagree) to 5 (strongly agree). Besides, this study developed a test to assess students' procedural knowledge of assembling the charcoal battery in the pretest and posttest session. In specific, participants were asked to describe the procedure of assembling a charcoal battery with given materials. One point would be given to a correct description for each step. There are five steps in total. Up to five points would be given to a test.

3. Data Analysis and Results

3.1 Learning outcomes

SPSS 20.0 were used to analyze the collected data. The Cronbach's α reliability of scales used in this study were 0.67 (TAM scale) and 0.95 (Flow scale), suggesting modest to high reliability. For the technology acceptance beliefs, the participants generally think that the game was useful to support their learning (M_{PU} = 3.61) while they might not evaluate the game as easy to play (M_{PEU} = 3.01). For the flow antecedents, the participants evaluated the game as of challenge (*M* = 3.50), with clear goal (*M* = 3.72), providing feedback (*M* = 3.67), controllable (*M* = 3.40), and playable (*M* = 3.47). On the other hand, the participants generally reported positive flow experience as the means of the four constructs were all exceed 3.00.

A t-test of pretest and posttest was conducted to address the learning outcomes after play the game. Result suggested that the participants develop better knowledge about the assembling the charcoal battery (t=2.728, $p < 0.05$). Further correlation analyses were conducted to reveal the correlation among constructs. Results suggested that perceived ease of use were correlated with playability ($r = .497$, $p < 0.05$) and autotelic experience ($r = .579$, $p < 0.01$).

3.2 Individual differences

In educational research, individual differences have been regarded as an influential factor (Yukselturk & Bulut, 2009). Game-related research also suggested female and male exhibit different evaluation of game and behavioral patterns (DeLeeuw & Mayer, 2011; Yee, 2006). Moreover, this study adapted sense of directions as individual difference since the primary feature of the game is to explore the virtual maze that requires players to explore the surrounding space. Therefore, this study conducted further analyses to address the plausible individual differences among research constructs.

The results indicated that male, in contrast to female, showed higher evaluation of game feedback ($t = 2.12$, $p < 0.05$), control ($t = 2.44$, $p < 0.05$), and playability ($t = 2.03$, $p < 0.05$). Gender differences were not found in other research constructs. Regarding the plausible effects of SOD, our results showed that group with better sense of directions (higher 50% of the SOD scores, n=11) evaluate the game with clear goal (t=2.25, $p < 0.05$) and more controllable ($t = 2.23$, $p < 0.05$). Moreover, the group of better SOD also reported higher evaluation of the usefulness of the game ($t = 2.73$, $p < 0.05$). The difference of learning outcomes was not found between the students with different level of SOD. The interpretation and discussion of these results are to be presented in the following section.

4. Conclusion and subsequent research

Computer games could be one of the most popular technologies that have been used extensively day to day, especially for youth and young adults. To arouse learner's motivation to learning, increasing attention has been paid to the application of computer games in educational context. Moreover, with the advancement of graphical computing power, nowadays, computer games are able to simulate the real world objects and immersing environment for players to explore. This study developed an educational 3D adventure game to simulate the procedure of assembling a charcoal battery and conducted a preliminary experiment to assess the effectiveness of the game to support learning and collect learners' reactions for further game development.

First of all, the result suggested that the educational game helped participants better understand the procedure of assembling the charcoal battery. In the posttest, participants generally gained higher score, which indicated they are more familiar with the procedure of assembling a charcoal battery. This result provided a preliminary support for the effectiveness of the game in this study. Previous study suggested that students tend to participate in the simulation game in a superficial manner. However, simulation game was considered an ideal training tool to intrigue learners' engagement and intrinsic motivation with adequate instructional supports (Liu et al., 2011). Moreover, in science education, computer simulation can be used to improve students' to be familiar with the procedure of laboratory activities before the actual lab activity sessions (Rutten et al., 2012). The computer simulation can be helpful for students to be familiarized with the abstract concepts and complicate procedure, which reflected in improved learning outcomes. By incorporating the game elements, as the 3D adventure in this study, the level of learners' interest in learning and engagement in the learning process are expected to be increased (Chang et al., 2012; Hwang, Wu, & Chen, 2012; Liu et al., 2011).

As typical gamers are more likely to be male (Griffiths, Davies, & Chappell, 2004) and individual differences are an important factor in educational research, this study further conducted a mean difference test of the research constructs for gender. Results indicated there were gender differences in three flow antecedents, namely the feedback, control and playability. This result might due to the different presences of the game content between male and female. Scoresby and Shelton (2011) found that female might not like the killing content in the first person perspective game, such as shooting monsters. In turn, female might possess lower perception of presence in the game and thus results in lower engagement in learning and learning performance. The game in this study is a Doom-like 3D adventure game. While players wandering around the 3D maze, they will encounter randomly appeared monsters and have to fight with them to reach the gates and complete the game goal. The incorporation of monsters is to increase the extent of challenge and excitement in game, which were considered important antecedents of flow experience. However, female might not like such game content. As a result, they might value the game less playable and controllable and neglect the feedback in the game. Therefore, gender differences in the game type and content should be considered while design an educational game in order to improve the engagement of learners.

Moreover, the game in this study is a 3D adventure game. To achieve the game goal, players have to collected the charcoal battery components scattered in the virtual 3D maze. Results of this study showed that students with better SOD score not only more likely to think of the game as useful to support learning, but also better understand the goal of the game and evaluate the as more controllable than those who have lower SOD score. Better SOD helps players to capture the way to explore the 3D virtual world. By knowing where they are and where to go, they can more easily to collect the needed components and use the assembled charcoal battery to go through the correct gates to achieve the game goal. On the contrary, without SOD, players might feel bored with the game as they can be lost in the maze and fail to advance to the new spaces. Nonetheless, this study didn't find the difference of learning outcomes between students of higher level SOD and lower level SOD. The small sample size and short game session (25 minutes) might pose limitation on the diversity of the learning outcomes. This study would subsequently conduct a larger scale of experiment to address this issue.

Despite results of this study showed significant improvement of the learning outcomes, however, in the preliminary version of the game, the proper scaffolding of the subject-domain knowledge was not incorporated. Without adequate feedbacks, students might mostly adopt trial-and-error strategy to achieve the game goal even though they have engaged in playing the game. With proper guidance and scaffolding, students might be able to reflect on the subject that the game is to help them to learn instead of just engaging in playing the game. Previous study also suggested that besides the game content, the success of incorporating game to support learning require adequate instructional support (Wouters & van Oostendorp, 2013).

Lastly, results of this study suggested that SOD is an influential factor in affecting players' evaluation of the game and their extent of engagement with the 3D adventure game. Despite the first person perspective and the immersive virtual environment can be helpful to increase the perception of presence, players with better SOD are more likely to grasp the game goals and control the process of gaming. The in-depth engagement with the game could help them learn better. However, these findings also brought up another consideration in developing the 3D adventure game for support learners without good SOD for learning. How to design the game content and control as well as instruction strategy to address this individual difference worth further exploration.

5. Research Limitations

The primary purpose of this study is to assessing learners' experience and learning outcomes with a 3D simulation game for chemistry learning. In the experiment of this study, students were allowed to freely play the coal battery for 25 minutes. However, the length time might not be sufficient for students to experience flow. Students might need more time to learn how to operate the game and hone their skills to meet the challenges in the game as a prerequisite condition of flow experience (Csikszentmihalyi, 1994). In our subsequent research, students will be allowed to play the 3D simulation game in a longer session. Meanwhile, they skills to control the game will also be examined to address the effect of individual difference to flow experience. Moreover, the small sample size might pose limitation to the interpretation of current results of this study. In the future study, more samples are to be collected to improve the reliability of research results. More individual differences, such as game experiences, game preferences, are to be incorporated as control variables. Lastly, the results of current research are to be employed to improve the future version of the game and the design of the instruction strategy to help students learn better.

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Reference

Amory, A., Naicker, K., Vincent, J., & Adams, C. (1999). The Use of Computer Games as An Educational Tool: Identification of Appropriate Game Types and Game Elements. *British Journal of Educational Technology*, 30(4), 311-321.

Chang, K.-E., Wu, L.-J., Weng, S.-E., & Sung, Y.-T. (2012). Embedding Game-Based Problem-Solving Phase Into Problem-Posing System For Mathematics Learning. *Computers & Education*, 58(2), 775-786.

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

Davis, F. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly*, 13(3), 319-340.

de Freitas, S., Earp, J., Ott, M., Kiili, K., Ney, M., Popescu, M., Stanescu, I. (2012). Hot Issues in Game Enhanced Learning: The GEL Viewpoint. *Procedia Computer Science*, 15(0), 25-31.

de Jong, T. (1991). Learning and instruction with computer simulations. *Education and Computing*, 6(3-4), 217-229.

DeLeeuw, K. E., & Mayer, R. E. (2011). Cognitive Consequences of Making Computer-Based Learning Activities More Game-Like. *Computers in Human Behavior*, 27(5), 2011-2016.

Griffiths, M. D., Davies, M., & Chappell, D. (2004). Online Computer Gaming: A Comparison of Adolescent And Adult Gamers. *Journal of Adolescence*, 27(1), 87-96.

Hegarty, M., Richardson, A. E., Montello, D. R., Lovelace, K., & Subbiah, I. (2002). Development of A Self-Report Measure of Environmental Spatial Ability. *Intelligence*, 30(5), 425-447.

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.

Huang, W.-H. (2011). Evaluating Learners' Motivational and Cognitive Processing in An Online Game-Based Learning Environment. *Computers in Human Behavior*, 27(2), 694-704.

Hwang, G.-J., Wu, P.-H., & Chen, C.-C. (2012). An Online Game Approach For Improving Students' Learning Performance in Web-Based Problem-Solving Activities. *Computers & Education*, 59(4), 1246-1256.

Kiili, K. (2005). Digital Game-Based Learning: Towards An Experiential Gaming Model. *The Internet and Higher Education*, 8(1), 13-24.
Kiili, K. (2006). Evaluations of An Experiential Gaming Model. *Human Technology*, 2(2), 187-201.
Liu, C.-C., , Cheng, Y.-B., & Huang, C.-W.. (2011). The Effect Of Simulation Games on The Learning of Computational Problem Solving. *Computers & Education*, 57(3), 1907-1918.
Pasin, F., & Giroux, H. (2011). The Impact of A Simulation Game on Operations Management Education. *Computers & Education*, 57(1), 1240-1254.
Rutten, N., van Joolingen, W. R., & van der Veen, J. T. (2012). The Learning Effects of Computer Simulations in Science Education. *Computers & Education*, 58(1), 136-153.
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.
Wouters, P., & van Oostendorp, H. (2013). A Meta-Analytic Review of The Role of Instructional Support In Game-Based Learning. *Computers & Education*, 60(1), 412-425.
Wu, W.-H., Chiou, W.-B., Kao, H.-Y., Hu, C.-H., & Huang, S.-H. (2012). Re-Exploring Game-Assisted Learning Research: The Perspective of Learning Theoretical Bases. *Computers & Education*, 59(4), 1153-1161.
Yee, N. (2006). Motivations for Play in Online Games. *CyberPsychology & Behavior*, 9(6), 772-775.
Yukselturk, E., & Bulut, S. (2009). Gender Differences in Self-Regulated Online Learning Environment. *Journal of Educational Technology & Society*, 12(3), 12-22.