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Learning behavior and achievement analysis of a digital game-based learning approach integrating mastery learning theory and different feedback models

Kai-Hsiang Yang

Department of Mathematics and Information Education, National Taipei University of Education, Taipei, Taiwan

ABSTRACT

It is widely accepted that the digital game-based learning approach has the advantage of stimulating students’ learning motivation, but simply using digital games in the classroom does not guarantee satisfactory learning achievement, especially in the case of the absence of a teacher. Integrating appropriate learning strategies into a game can better enhance the learning performance. Therefore, in this study, a mastery theory-based digital game with different feedback models was developed to compare the differences in the learning behavior of students using the two feedback models. Lag sequential analysis was then applied to identify the sequential behaviors that are statistically proven to have impact. The results of the experiments and behavior analysis show that, with proper design of the game, students in both feedback methods can achieve the same learning performance as that in the conventional learning method with a teacher involved. Moreover, students in the Regular Feedback Group reviewed the learning material more times than those in the Corrective Feedback Group, which seemed to mitigate the drawbacks of the regular feedback. This result suggests that a proper game design will be able to achieve effective learning and is robust in terms of feedback models.

KEYWORDS

Learning behavior; game-based learning; mastery learning theory; feedback models; learning achievement analysis

1. Introduction

The application of digital games to education is widely believed to stimulate internal motivation and interest among students (Malone & Lepper, 1987; Ricci, Salas, & Cannon-Bowers, 1996) as well as enhancing learning achievement and improving learning attitudes (Bai, Pan, Hirumi, & Kebritchi, 2012; Ke & Grabowski, 2007; Klawe, 1999; Papastergiou, 2009; Rosas et al., 2003; Shin, Sutherland, Norris, & Soloway, 2012). However, simply using digital games in the classroom does not guarantee satisfactory results. Kebritchi (2008) argued that instructional strategies and theories must be applied to the design of educational games for the games to enhance learning. Improper design may lead to negative consequences (Charsky & Ressler, 2011).

Bloom’s (1968) mastery learning theory posits that the great majority of students could learn successfully if they were provided with organized and structured instruction as well as feedback to correct mistakes throughout the learning process. This approach focuses on frequent formative assessments and appropriate feedback to help students continually improve throughout an individualized learning process. In a traditional educational setting, instructors most often administer formative assessments in the form of pen-and-paper tests. However, students are typically unwilling to
take these tests and consider them boring (Castellar, All, de Marez, & Van Looy, 2015). In addition, instructors are often unable to provide timely and meaningful feedback when administering these assessments (Wang, 2011). Therefore, the mastery learning approach may be difficult to implement in traditional instructional classrooms.

Digital games can be designed to increase the motivation and willingness of students to answer questions. More notably, they can provide students with accurate feedback (Tsai, Tsai, & Lin, 2015; Ventura & Shute, 2013), which facilitates the mastery learning goal of correcting mistakes through feedback. As a critical element of educational games, feedback plays a key role in a learning atmosphere that incorporates digital games. It enables students to actively learn through trial and error, and decreases uncertainty, thus producing learning-oriented behavior (Mayer & Johnson, 2010; Oblinger, 2010). In addition, immediate feedback is one of the factors that produces a state of flow (Csikszentmihalyi, 1975), which stimulates the motivation to learn and facilitates learning achievement among students. Therefore, we assert that digital games and mastery learning theory should be combined in an instructional medium. In addition to providing educational content through games, this medium can motivate students to practice regularly and provide instant feedback that assists students in correcting their own mistakes, thus supporting their personal growth.

Numerous past studies have examined how different feedback models in games affect learning achievement. For example, Hwang, Chiu, and Chen (2015) developed a money management game. The goal was for students to determine the most cost-effective of three different management methods, and feedback was provided through awarding points. If students made the best choice, they won a scroll and points; if they made the wrong choice, their score did not increase and may have even decreased. This feedback model stimulated student thinking. Some researchers (Chu, Yang, & Chen, 2015; Hwang, Wu, & Ke, 2011; Liu & Lee, 2013) have integrated a concept map into the feedback graphics in the game interface, enabling students to systematically organize information obtained in the game. Tsai et al. (2015) examined the effect of feedback timing on junior high students’ learning about energy. The results showed that providing immediate elaborated feedback was more effective for knowledge acquisition than not providing it. In these studies, the games acted as a practice tool after a teacher had provided instruction and were not the primary learning platform. In contrast to this approach, we examined whether a game that integrates the mastery learning theory can produce the same learning achievement as teacher instruction.

In this study, a mastery theory-based digital game with different feedback models was therefore developed to compare the differences in the learning behavior of students using the two feedback models. Lag sequential analysis (Bakeman & Gottman, 1997; Hou, 2015; Yang, Chen, & Hwang, 2015) was then applied to identify the sequential behaviors that are statistically proven to have an impact. The research questions include:

1. Is there any difference among the mastery theory-based digital game with different feedback modes in terms of the students’ learning behavior?
2. Is there any difference among the mastery theory-based digital game learning methods and the conventional learning method in terms of students’ learning achievements, attitude, and cognitive load?

2. Literature review

2.1. Mastery learning theory

The mastery learning theory is based on a cognitive behavioral approach. Its objective is to help each student achieve the same, high level of learning by providing an appropriate learning atmosphere for each student, based on his or her individual differences (Kazu, Kazu, & Ozdemir, 2005). Bloom (1968) believed that the great majority of students are able to master what an instructor teaches, and that an instructor’s goals should be to illuminate the key points of the subject and provide methods and
materials that can assist the greatest number of students to achieve mastery of that subject. Individual differences must be considered to enable each student to reach their full potential. Bloom also stated that instructors must consider five factors: (1) aptitude for particular types of learning or the amount of time required for each student to achieve mastery; (2) quality of instruction; (3) ability to understand instruction; (4) perseverance, or the amount of time that each student is willing to spend on learning, which is affected by attitude and interest; and (5) time provided for learning. The last factor is considered the key to mastery learning.

Bloom’s theory was deeply influenced by John B. Carroll’s “A Model for School Learning”, published in 1963. Traditional views of aptitude define the term as the level of learning that a student can achieve within a specified amount of time. Based on this definition, students are classified as either good or bad learners. Carroll proposed, instead, to define aptitude as the amount of time required for a student to achieve a specified level of learning. Thus, aptitude is a measure of learning efficiency. From this perspective, each student has the potential to learn, and the difference lies in the speed of learning (Guskey, 1980).

Guskey (1980) explained how Bloom combined Carroll’s concept with Bloom’s own observations of teaching to develop the mastery learning theory. Application of the mastery learning theory to real educational settings involves a series of processes: instructors first divide the course material into one-week units. After teaching the unit, instructors administer tests to ascertain the students’ learning progress. The purpose of these tests is to help the instructor provide appropriate feedback, determine which concepts have not yet been mastered, and offer students specific suggestions to help them overcome their learning difficulties. These “correctives” can include requiring students to reread a certain passage or providing alternative learning resources. The emphasis of this approach is that education must include repeated feedback and correctives to enable students to master the material.

Guskey (2007) also provided a specific example of the mastery learning process: after receiving instruction in the first unit, all students are administered Formative Assessment A. Passing this assessment indicates that the students have mastered the first unit, and instructors can provide enrichment activities to these students. Students who do not pass this assessment are provided with correctives, after which they take Formative Assessment B. After these students pass Formative Assessment B, all students progress on to Unit 2 simultaneously, as shown in Figure 1.

Therefore, in an environment that employs mastery learning theory, the primary challenge is to provide enough time, appropriate feedback, and corrective instructional strategies. A digital game can manage the individual learning pace of each student and provide immediate feedback; thus, it is an ideal tool for implementing mastery learning theory. To understand how a digital game that integrates mastery learning theory affects learning achievement, we examined how it differs from a traditional instructional approach.

Although Bloom’s mastery learning theory has been widely used in conventional educational-related research, we did not find any studies illustrating that this theory has been applied to educational games. Most studies of digital game-based learning (Chu et al., 2015; Hwang et al., 2011, 2015; Liu & Lee, 2013; Tsai et al., 2015) have directly investigated the differences among different feedback models, and there has, to date, been no in-depth discussion in terms of the mastery learning theory.
2.2. Digital game-based learning and feedback

Educational digital games enable students to operate them and learn in the virtual environment of the game. This is expected to stimulate knowledge acquisition and development of cognitive skills (Erhel & Jamet, 2013). Many researchers have determined the factors necessary for successful games. For example, Malone (1981) postulated that games must feature challenge, fantasy, and curiosity to fully stimulate the internal motivation of students. Kiili (2005) advocated the importance of including immediate feedback, clear goals, and challenges that are matched to the student’s skill level in games, while Mayer and Johnson (2010) indicated that digital games used for educational purposes often have four key characteristics: rule-based, responsive (i.e. they must provide responses to the student’s behaviors), challenging, and cumulative (i.e. they must produce a cumulative increase in learning outcomes). These key elements provide students with a sense of control and self-efficacy and produce learning-oriented behaviors to promote learning achievement. According to the aforementioned studies, feedback (or responses) is an indispensable element of educational games which can promote positive learning outcomes (Hanus & Fox, 2015; Papastergiou, 2009).

In Interactive instruction and feedback, Dempsey and Sales (1993) provided three definitions of feedback: (1) motivation or incentive to increase speed or accuracy; (2) a stimulus–response interaction that produces a state of satisfaction on the basis of Thorndike’s Law of Effect; and (3) information used by students to confirm or correct previous responses. Studies of digital game-based learning have examined action–adventure games such as Monkey Tales. Its feedback mechanism has been shown to improve the speed and accuracy of students’ arithmetic calculations (Castellar et al., 2015). These studies have also examined role-playing games (RPGs), which are a type of game that emphasizes a narrative containing fictional events, situations, and contexts. The storyline is often revealed by a series of missions. Players must explore within the game and speak to non-player characters to gather clues. These games feature complex feedback and reward mechanisms and can offer a self-sustaining, highly motivating, and immersive environment (Cornillie, Clarebout, & Desmet, 2012).

Although all games contain feedback mechanisms (e.g. awarding points or completing levels) that inherently increase motivation, educational researchers place more value on instructive feedback that is more closely tied to learning and can provide information to students. Collins, Carnine, and Gersten (1987) defined corrective feedback as the feedback that appears after players make a mistake and identified three types of such feedback: (1) minimal feedback, which tells students only whether their answers are right or wrong; (2) basic feedback, which tells students whether their answers are right or wrong and provides the correct answer if the students are wrong; and (3) elaborated corrective feedback, which provides students who answer incorrectly with a series of rules or hints to help them find the correct answers. Collins et al. compared the effects of elaborated corrective feedback and basic feedback on learning achievement and determined that the former resulted in stronger performance on both posttests and maintenance tests. In addition, Muis, Ranellucci, Trevors, and Duffy (2015) compared the effects of immediate feedback versus no feedback and positive versus negative feedback on learning attitudes among kindergarteners. They reported that students who provided the wrong answer liked positive feedback but disliked negative feedback. They also reported that receiving feedback from technological media resulted in higher academic performance compared with not receiving feedback. Hooshyar et al. (2016) examined the timing of feedback, categorized as immediate elaborated feedback or no immediate elaborated feedback. They determined that the former was the optimal design for single-player tic-tac-toe games and could stimulate acquisition of programming knowledge. Besides, Hsia, Huang, and Hwang (2016) explored the influence of different online peer-feedback approaches for students to learn dance movements. Their results showed that the hybrid model of combining peer commenting and peer rating can greatly promote the participation of the learners.

In addition, numerous other studies have compared game feedback types (Burgers, Eden, van Engelenburg, & Buningh, 2015; Serge, Priest, Durlach, & Johnson, 2013), but none so far have
performed a deep analysis of the causes of the differences between results. Therefore, we compared two types of corrective feedback mechanisms and closely examined their effects on in-game learning behaviors.

3. Game design

To help students effectively learn the domestic and foreign food culture unit in social studies, we proposed a learning approach based on developing digital games that incorporate mastery learning theory and different feedback models. We worked with an elementary school to introduce the customs and food cultures of Japan, Thailand, India, Germany, and Turkey.

Next, we used the RPG Maker VX software program developed by Enterbrain to create a game called The Little Five-Star Chef. In this game, players take on the role of a little boy who wants to receive certification as a chef. To accomplish the goal, he needs to master the cooking skills and knowledge of the food from five different countries. At the beginning of the game, the boy first sees five houses, each of which represents customers from one country, and he has to complete the requests from all five houses to receive the certificate. The player can choose which house (country) he wants to learn first, but he has to finish the learning processes in sequence, that is, he needs to finish all of the requests of the first house he chooses before entering the next one. In each house, the boy first needs to be familiar with the food and culture of that country and then he has to purchase the necessary ingredients of the dishes from the market. In the market, he cannot purchase the ingredients until he has correctly answered all of the questions regarding that country. Consider Figure 2, for example; the boy first learns the information about Turkish cuisine. Then he goes to the market to buy the ingredients he needs. He cannot acquire the ingredients until he has correctly answered the questions regarding Turkey, such as “Which of the following is incorrect regarding the Islamic fasting month?” Once he has collected all of the necessary ingredients for the dishes, he needs to go back to the kitchen. Then he can do the cooking to make the delicious dishes to complete the task in that house. However, if he does not collect all

![Game screen shots.](image)

Figure 2. Game screen shots.
of the necessary ingredients, as shown in the bottom-right panel of Figure 2, he will not be able to continue the cooking procedure.

In this study, the Bloom’s mastery learning theory was integrated into the design of the game. According to the mastery learning process provided by Guskey (2007), we first divided the learning content into several smaller units, and then arranged related learning content into the game for the students to learn. After receiving instruction in the first unit, students can challenge themselves by taking the formative assessment in the game. Passing this assessment indicates that they have mastered the first unit, and our game can provide them with related activities. Students who do not pass this assessment are provided with feedback and correctives, after which they can take another formative assessment. After they pass the formative assessment for the first unit, they can progress to the next one.

The detailed in-game learning process is shown in Figure 3. After beginning the game, students first read the course material for a unit (e.g., Japanese food culture) and then answer the comprehension questions. If they answer correctly, they receive the corresponding feedback and can begin work on Unit 2 (e.g., Thai food culture). If they answer incorrectly, they receive the corresponding feedback and are asked to answer additional comprehension questions. The students have to answer the questions correctly before moving on to the next unit. To ensure consistency and fairness in the learning content, students who answer questions correctly are not provided with additional content. Two versions of the games that were identical except for the feedback model were designed in this study. Referencing the work of Collins et al. (1987), the feedback given was either minimal feedback or elaborated corrective feedback. The former conveyed only whether the answer was correct or incorrect, whereas the latter conveyed whether the answer was correct or incorrect and provided detailed textual explanations to help the student recall the educational content. Figure 4 shows the two different feedback models in the game.

4. Experiment design

4.1. Participants

A total of 75 students from 3 fifth-grade classes of an elementary school in northern Taiwan participated in this quasi-experimental study. The three classes were randomly assigned as Experimental Group A, Experimental Group B, or the Control Group. Experimental Group A learned from a mastery theory-based digital game with regular feedback and is called the “Regular Feedback

Figure 3. Learning process in the digital game-based learning system.
Experimental Group B learned from a mastery theory-based digital game with corrective feedback and is called the “Corrective Feedback Group (CFG)”. The control group learned from a conventional technology-enhanced learning approach that used slides and is called the “Conventional Group (CG)”.  

4.2. Research tools  
4.2.1. Materials and instruments  
The research tools used were a social studies pretest and posttest, a pretrial and posttrial learning attitude questionnaire, and a cognitive load questionnaire. The social studies pretest and posttest were developed by two elementary school social studies teachers with over 10 years of teaching experience. The objective of the pretest was to assess the students’ pre-existing knowledge of foreign food cultures; for example: “Is Japan ramen modified from Italian pasta?” The objective of the posttest was to assess students’ understanding and knowledge acquisition of foreign food cultures; for example, “Which of the following is not a feature of Thai taste? (1) light (2) sour (3) salty (4) spicy.” Both tests comprised true or false and multiple choice questions, and the highest possible score was 100.

The pretrial and posttrial learning attitude questionnaire was adapted from the questionnaire developed by Hwang, Yang, and Wang (2013). It comprised seven items (e.g. “I feel that learning this unit was meaningful and worthwhile”) and was scored on a 5-point Likert scale, with 5 representing strongly agree and 1 representing strongly disagree. Cronbach’s α of the questionnaire was .79, indicating satisfactory internal consistency.

The effect of the different game feedback models on cognitive load was one of the focal points of this study. We used the cognitive load questionnaire developed by Hwang et al. (2013), who based the questionnaire on previous measurement tools by Paas (1992) and Sweller, Van Merriënboer, and Paas (1998). The questionnaire comprised five items that assessed mental load and three items that assessed mental effort. Responses were scored on a 5-point Likert scale. All questions were worded in reverse. For example, one item for mental load is “It makes me tired to answer the questions in this activity.” Another item for mental effort is “The presentation or explanation of the teaching content gives me a lot of pressure.” Thus, a higher score represented a heavier cognitive load. Cronbach’s α values were .85 for mental effort and .86 for mental load, indicating satisfactory internal consistency.

4.2.2. Behavior recording module  
To understand the effect of different feedback models on the students’ game behavior, we employed a coding scheme to perform a quantitative content analysis (Rourke & Anderson, 2004). All possible behaviors that the students could engage in within the game were predefined in the coding scheme.
Table 1. Coding scheme of in-game behaviors.

<table>
<thead>
<tr>
<th>Code</th>
<th>Phase</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>Read</td>
<td>Read textbook about foreign food culture</td>
</tr>
<tr>
<td>C</td>
<td>Cookbook</td>
<td>Read a foreign recipe</td>
</tr>
<tr>
<td>O</td>
<td>Correct</td>
<td>Answer correctly</td>
</tr>
<tr>
<td>I</td>
<td>Incorrect</td>
<td>Answer incorrectly</td>
</tr>
<tr>
<td>B1</td>
<td>Feedback1</td>
<td>Minimal feedback Behavior unique to the Regular Feedback Group</td>
</tr>
<tr>
<td>B2</td>
<td>Feedback2</td>
<td>Elaborated corrective feedback Behavior unique to the Corrective Feedback Group</td>
</tr>
<tr>
<td>S</td>
<td>Start</td>
<td>Start unit activity</td>
</tr>
<tr>
<td>M</td>
<td>Complete</td>
<td>Complete unit activity</td>
</tr>
</tbody>
</table>

(Table 1), comprising R (read) and C (cookbook), which represent reading about foreign food cultures or recipes; O (correct) and I (incorrect), which represent answering a question correctly or incorrectly; B1 (feedback1), which represents minimal feedback and is unique to the RFG, or B2 (feedback2), which represents elaborated corrective feedback and is unique to the CFG; and S (start) and M (complete), which represent starting or completing the unit activities, respectively. Any instances of these pre-encoded behaviors were automatically recorded in the log database of the game.

4.3. Experimental procedure

The experiment took place in three stages (Figure 5). In the first stage, all three groups completed the social studies pretest and the learning attitude pretrial questionnaire. In the second stage, the RFG and the CFG learned from digital games that integrated mastery learning theory and different feedback models, while the CG learned from a conventional technology-enhanced learning approach whereby a teacher used slides to convey the course material. The contents in the slides were the same as the learning materials in the game, but the students did not need to learn different recipes. This group was also provided with a formative assessment the same as that in the game but using pen and paper. In the last stage, all three groups completed the social studies posttest, the learning attitude, and the cognitive load questionnaire.

5. Results

5.1. Analysis of learning effectiveness

To investigate the effects of the proposed approaches on the students’ learning performance, a one-way analysis of covariance (ANCOVA) was performed. The analysis results showed that there was no significant difference in the regression coefficient homogeneity test for learning achievements ($F = 0.393, p = .677 > .05$) or for learning attitude ($F = 1.028, p = .364 > .05$) among the three groups, which indicates that ANCOVA could be carried out.

The analysis results of the ANCOVA showed no significant difference in learning achievements ($F = 0.389, p = .679 > .05$; Table 2) or learning attitude ($F = 0.537, p = .587 > .05$; Table 2) among the three different groups of students. This indicates that in addition to the conventional technology-enhanced learning approach with a teacher involved, the mastery theory-based digital game with two different feedback models did not have a significantly different effect on student learning effectiveness.

Paas (1992) believed that cognitive load is a multidimensional concept, comprising the dimensions of mental load and mental effort, and that a self-reporting scale completed by students could provide an in-depth exploration of the concept. The analysis results of the mental load and mental effort dimension are shown in Table 3. The results showed no significant difference in the questionnaire among the three different groups of students. This indicates that the difficulty of the material was not significantly different for the two groups of students that used the game-based learning approaches. Furthermore, all of the students that used any of the three learning approaches expended the same amount of effort.
5.2. Analysis of behavioral patterns

On the basis of the lag sequential analysis procedure, we first calculated the frequency of the behavior sequences. In Table 4, initial behaviors are listed in the first column and consecutive actions are listed in the first row. The numbers in the cells represent the number of times the corresponding combination of behaviors occurred. For example, in the RFG, the frequency of the sequence R then C was 47; in the CFG, the frequency of the sequence R then C was 67.

![Diagram](image_url)
As determined by a series of matrix operations to calculate the adjusted residuals, the frequency of a sequence of behaviors was statistically significant ($p < .05$) if the $z$-score of the sequence was greater than or equal to 1.96. Table 5 lists 16 sequences that were statistically significant for the RFG (i.e. $R \rightarrow R$, $R \rightarrow C$, $R \rightarrow S$, $C \rightarrow C$, $C \rightarrow O$, $C \rightarrow I$, $O \rightarrow B_1$, $I \rightarrow B_1$, $B_1 \rightarrow C$, $B_1 \rightarrow O$, $B_1 \rightarrow I$, $B_1 \rightarrow M$, $S \rightarrow R$, $S \rightarrow C$, $M \rightarrow R$, $M \rightarrow S$) and 13 sequences that were statistically significant for the CFG (i.e. $R \rightarrow R$, $R \rightarrow C$, $C \rightarrow C$, $C \rightarrow O$, $C \rightarrow I$, $O \rightarrow B_2$, $I \rightarrow B_2$, $B_2 \rightarrow C$, $B_2 \rightarrow O$, $B_2 \rightarrow I$, $B_2 \rightarrow M$, $S \rightarrow R$, $M \rightarrow S$).

All statistically significant behavior sequences in Table 5 were then diagrammed. The numbers in Figure 6 represent $z$-scores, the arrows represent the order of behaviors, and the thickness of the arrow represents the relative significance. An examination of the categories of behavior codes shows that because the game design was based on mastery learning theory, students in both experimental groups proceeded according to the course of instruction preplanned by the researchers. This sequence, $S \rightarrow R$, $R \rightarrow C$, $C \rightarrow O$, $C \rightarrow I$, $I \leftrightarrow B_1$, $O \leftrightarrow B_1$, and $M \rightarrow S$, indicates that the students read the material (textbooks and recipes), attempted to answer the questions, and received the appropriate feedback. If they answered the questions correctly, they began the activities of the next unit. In addition, regardless of the feedback model, the number of repeated correct or incorrect attempts was approximately equal. In the RFG, the sequences $I \leftrightarrow B_1$ and $O \leftrightarrow B_1$ were highly significant. The same sequences were also highly significant in the CFG. This suggests that the proportion of incorrect answers did not necessarily decrease because the game provided clearer elaborated corrective feedback.

However, significant differences in behavior were determined between the RFG and the CFG. Behavior sequences $M \rightarrow R$ and $S \rightarrow C$ were exhibited by the RFG, but not by the CFG. Because the

### Table 4. Frequency transition table of the two groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>R</th>
<th>C</th>
<th>O</th>
<th>I</th>
<th>B1</th>
<th>B2</th>
<th>S</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>RFG 54</td>
<td>47</td>
<td>50</td>
<td>28</td>
<td>0</td>
<td>18</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>CFG</td>
<td>42</td>
<td>67</td>
<td>30</td>
<td>25</td>
<td>0</td>
<td>7</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>RFG 18</td>
<td>58</td>
<td>101</td>
<td>51</td>
<td>0</td>
<td>8</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>CFG</td>
<td>21</td>
<td>71</td>
<td>109</td>
<td>80</td>
<td>0</td>
<td>7</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>RFG 0</td>
<td>0</td>
<td>0</td>
<td>938</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>CFG</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>691</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>RFG 0</td>
<td>0</td>
<td>0</td>
<td>442</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>CFG</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>462</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>RFG 20</td>
<td>112</td>
<td>784</td>
<td>360</td>
<td>0</td>
<td>1</td>
<td>103</td>
<td></td>
</tr>
<tr>
<td>CFG</td>
<td>14</td>
<td>144</td>
<td>549</td>
<td>355</td>
<td>0</td>
<td>0</td>
<td>91</td>
<td></td>
</tr>
<tr>
<td>B2</td>
<td>CFG 96</td>
<td>16</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>CFG 88</td>
<td>10</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

### Table 5. Adjusted residuals table ($z$-scores) of the two groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>R</th>
<th>C</th>
<th>O</th>
<th>I</th>
<th>B1</th>
<th>B2</th>
<th>S</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>RFG 12.47*</td>
<td>9.29*</td>
<td>−1.05</td>
<td>0.29</td>
<td>−12.16</td>
<td>4.81*</td>
<td>0.94</td>
<td></td>
</tr>
<tr>
<td>CFG</td>
<td>10.72*</td>
<td>13.10*</td>
<td>−1.87</td>
<td>−0.38</td>
<td>−10.77</td>
<td>0.85</td>
<td>−2.16</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>RFG 0.97</td>
<td>10.98*</td>
<td>5.33*</td>
<td>4.02*</td>
<td>−13.16</td>
<td>0.23</td>
<td>−1.69</td>
<td></td>
</tr>
<tr>
<td>CFG</td>
<td>0.93</td>
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*Statistically significant sequence.
RFG only received minimal feedback that stated whether their answers were correct or incorrect, we deduced that the students may have voluntarily reviewed the course materials (textbooks and recipes) to be more familiar with the content. In contrast, the CFG received elaborated corrective feedback, which means that if they answered incorrectly, they were able to review the course content. This may have caused the attitude that answering incorrectly was inconsequential because the game would display the right information. Thus, this may have decreased their active learning behaviors.

6. Discussion and conclusion

In this study, we have proposed a method for developing digital games that integrate the mastery learning theory and different feedback models. We examined the effect of digital game-based learning, without teacher instruction, on learning achievement compared with a conventional technology-enhanced learning method with a teacher involved. We also compared the differences between the students’ behavior patterns of the two experimental groups. Our results show that there is no
significant difference in learning achievements, learning attitudes, or cognitive loads among the three groups. This indicates that, with proper design of the game, students in the mastery theory-based digital game can effectively achieve the same learning performance as that in the conventional technology-enhanced learning method with a teacher involved. These findings suggest that with the help of appropriate learning strategies, digital games can produce positive effects on learning (Kebritchi, 2008). However, this is not the same as previous research results (Bai et al., 2012; Papastergiou, 2009) in which the learning performance in digital games was not significantly better than that in the conventional learning method. We can clarify the reasons from the results of the behavior analysis as follows.

First, the mastery theory was integrated into our game to arrange the learning path for students. When students answer correctly, they can proceed to the next phase of learning; otherwise they will receive feedback and try to answer again. According to the behavior patterns (S→R, R→C, C→O, C→I, I⇔B1, O⇔B1, M→S) in the RFG and the CFG, we can easily see that the students followed the learning path in the game. This is the main difference between digital game-based learning and conventional learning. Well-designed digital game-based learning can provide students with personal and appropriate feedback and exercise, but it is very difficult for a single teacher to do that in a conventional learning environment.

Although the game proposed in this study can provide appropriate feedback and exercises, the learning performance in the RFG and CFG was not significantly better than that in the conventional learning method. Through a behavioral analysis, we discovered why the present study produced these results. Both experimental groups continued to answer incorrectly after receiving feedback (I⇔B1, I⇔B2) at the same high frequency. From this, we inferred that the students in both experimental groups mostly guessed at the answers. We further inferred that these guessing behaviors were caused by the randomized display of questions. Although all the questions tested the same concept, the use of different questions increased the difficulty of the assessment. In addition, the game design did not include a mechanism for deducting points or character hit points for wrong answers. Thus, some students may have chosen answers at random.

Furthermore, a comparison of the RFG and the CFG showed no significant difference between providing minimal feedback and providing elaborated corrective feedback on the students’ learning achievements, learning attitudes, or cognitive loads. These findings contradict those of Collins et al. (1987), who reported that providing elaborated feedback with more information was more helpful to students. We can also identify the reason for this difference from the results of the behavior analysis. The behavioral transfer diagrams showed significant differences between the two experimental groups. The results showed that the RFG students reviewed the course material (M→R, S→C) more often than the CFG students did. This is because our game successfully raised the students’ interest and was designed not to penalize them when they answered incorrectly. As a result, students in the RFG checked and reviewed the learning material more times than those in the CFG so as to continue with the game, and thus this somehow mitigated the drawbacks of the regular feedback. From this result, we can find that students will automatically adjust their learning strategies according to the received feedback in the game. Therefore, it is very important for an educational game to provide multiple ways of learning so that students can develop their own learning strategies.

In conclusion, in this study, we first proposed a mastery theory-based digital game with different feedback models, and then applied lag sequential analysis to identify statistically important behaviors. Our results show that with proper design of the game, students in both feedback methods can effectively achieve the same learning performance as that in the conventional technology-enhanced learning method with a teacher involved. Moreover, students will automatically adjust their learning strategies according to the received feedback in the game. This result suggests that a proper game design will be able to achieve effective learning and is robust in terms of feedback models. Besides, this study was based on a foreign food culture unit in social studies that emphasized memory and comprehension. Future studies should explore whether other types of knowledge (e.g.
procedural knowledge) can be applied in game-based learning without teacher instruction and still yield similarly satisfactory learning outcomes.

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**Notes on contributor**

Dr. Kai-Hsiang Yang is currently an Associate Professor in the Department of Mathematics and Information Education at National Taipei University of Education in Taiwan. His research interests include digital game-based learning, information technology-applied instructions, data mining, and web-based learning.

**References**


