Design and development of a game to improve self-efficacy: A case study of addressing modes learning

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Abstract: The low self-efficacy has been an important issue in the design of instructional methods, and its negative effects are mainly shown by the reduced willingness to learn and the high dropout and failure rates. Game-based learning has received attention in the design of t instructional methods because of the combination of learning content and games. In this study, we use addressing modes learning in operation system course as a case object to explore the potential of improving the low self-efficacy by game-based learning. To this end, a side-scrolling video game was designed to complete the case study task to examine the effect of game-based learning on solving the low self-efficacy issue. According to the experimental results, there was no difference in learning achievement between the experimental group students who used game-based learning, and the control group students who used traditional learning methods. However, with similar scores in learning achievement, the experimental group students showed higher self-efficacy than the control group students. In addition, it was shown that the game-based learning approach did not impose additional cognitive load.
Keywords: Game-based learning, self-efficacy, addressing modes learning

1. Introduction

Self-efficacy in learning activities has long been of interest to researchers. Since this issue is closely related to students' learning achievement and psychological cognitions. For example, appropriate self-efficacy can help students reduce learning stress, increase learning efficiency and maintain interest and engagement in learning activities (Silveman & Casazza, 2000). Conversely, the negative effects of low self-efficacy are obvious. Students who spend long periods of time in low self-efficacy face higher levels of studying stress, exhibit avoidance behavior and tendency to boredom, which ultimately leads to high dropout rates (Martin & Marsh, 2003).

High dropout and failure rates in computer-related courses are a common problem (Gomes & Mendes, 2007), and Heward (2003) argues that students who face challenging and unfamiliar learning content are more likely to develop low self-efficacy, reducing motivation and willingness to learn. Meanwhile, Weina, Ping, & Shuai (2018) confirmed that the main challenges in computer courses come from abstracted concepts where knowledge points are dispersed and the intrinsic logic relationship between concepts is hard to find. Therefore, instructional methods that match the learning content receive attentions.

The conceptualization, design principles, and applications of game-based learning have gained great attention (Tobias, Fletcher, & Wind, 2014). Game-based learning is not a new thing, especially for contemporary students who are accustomed to electronic devices early on. In this study, addressing modes learning in operation system course is used as a case object to use game-based learning as an attempt to solve the issues of low self-efficacy that arises in computer-related courses.

2. Literature review

2.1 Addressing modes learning in operation system course

Operation system course is a core foundation course with many concepts, strong principles, and high degree of abstraction (Weina, Ping, & Shuai, 2018), which related to much hardware knowledge. As a result, high drop out and failure rates have been reported with focusing on much attentions (Gomes & Mendes, 2007). Addressing modes means the specification of data locations required by an operation. Also, mastering addressing modes involves thinking and reasoning that usually required for operation system learning. As one of difficulties in learning operation system, more demands for practicable lessons with reasonable learning approaches than purely theoretical ones have been made when learning addressing modes (Bolanakis et al., 2008). Faced with challenging learning content, it is more likely to have insufficient self-efficacy (Martin & Marsh, 2003).

2.2 Impact of low self-efficacy on learning activities

Self-efficacy theory originally stemmed from objective analysis on changes achieved in fearful and avoidant behavior. Bandura described self-efficacy is concerned with individuals' beliefs in their control over challenging demands (Bandura, 1994). Diverse effects are produced depending on various levels on self-efficacy. It was found that a strong sense of self-efficacy is highly correlated with improvement of human accomplishment (Maddux & Gosselin, 2012). Schunk (1995) reported that people with high self-efficacy regard difficult tasks as challenges to be mastered rather than as threats to be avoided. Intrinsic interest and deep engrossment in learning activities may be fostered easily with help of such self-efficacy (Zajacova, Lynch & Espenshade, 2005). Also, higher self-efficacy may reduce learning frustration, facilitate learner's effort and improve sustaining interest in challenging activities (Silverman & Casazza, 2000). Although self-efficacy has moderated relationship with learning performance, it is not necessarily that high self-efficacy leads to higher learning performance (Balkis, 2011). Davis (2009) found that people with higher self-efficacy have higher subsequent learning performance.

2.3 Challenges on game-based learning design

Application potential of game-based learning was ground in a mount of research. The acceptance of game-based learning has been widely taken in educational context. Among application benefits, facilitating learning by fostering multiple perspectives such as cognitive, affective, behavioral and sociocultural engagement is full of expectation from actual application (Jan et al., 2015). However, emphasis only on learning performance has been fading, in contrast to growing shift to a combination of learning and psychology effect. Notably, some questions were raised along with attention on how to make use of the game promise for education purposes, while taking balance of entertainment and learning in account.

Another challenge of converting learning objectives to game design is prominent. When designing game based on particular pedagogy that requires logical ability to understand abstractness, it will exacerbate the challenge of this conversation (Moreno-Ger et al, 2008). Pedagogical requirements driven by difficult leaning content may result in low willingness to persist involvement in learning tasks (Westwood, 2003). General learning difficulties can happen owing to inadequate or inappropriate teaching (Westwood, 2003), especially in the early stages of learning with complicated learning patterns that hard to determine reasons (Zhao, Hwang, & Yin, 2021).

Game designing lacks of consensus on uniform rules, because it involves of complicate game-design factors such as learning objectives, mechanism, fantasy value, interaction, freedom, narrative, sensation, challenges, sociality, and mystery (Shi & Shih, 2015). One of the most critical principles was presented by Shabalina et al. (2014), emphasizing that a sequence of game activities is structured by coming learning objectives and game activities. To support the effect embedding game in learning, meeting the needs of course with a focus on learning goals, feedback, and interaction in the game functions (Alaswad & Nadolny, 2015). So that, it is essential to consider learning attributes included of above game-design factors and game functions.

The studying questions are as follows:

- How to combine learning contents and game operational processes in game design?
- Could the developed game improve self-efficacy and academic achievement?
- Could the developed game bring additional cognitive load in solving low-efficacy issues?

3. Game system design and development

The game module includes (1) UI module, consists of navigation mode, content display, and basic controls. (2) Physics module, the game needs to interact with the performance of objects given physical characteristics, such as the size of the force when the character jumps. (3) Scene module, the terrain, level and character management in the game. When developing the game, the three modules were developed using the Unity game engine as the development tool. Firstly, use the physics system, graphics system and audio elements in Unity to develop scene module. Subsequently, in the built game scene, game characters are added and the character behavior and game logic in the scene are implemented through Unity scripts. Finally, use uGUI to design the game interaction interface, such as game effects. Next, the following two aspects will mainly be introduced: how to translate learning content into game elements and design core game modules.

3.1 Implement of learning content in the design of game system

Concepts and operational processes are the two main learning content when learning addressing modes. These can be further refined into: data locations, proper nouns and addressing operations. In game design and development, three learning content are translated into game maps, game terms and game activities respectively.

3.1.1 Correspondence between data locations and game maps

The storage and processing of data during addressing involves three main data locations: the CPU (processor), the memory and the auxiliary memory (hard disk). Firstly, there are direct and indirect ways of accessing data. CPU has direct access to memory data and no direct access to hard disk data. This indirect access to hard disk data by the CPU can only be done with the help of memory. Secondly, the method of data storage shown in Figure 1. Memory and hard disk data storage relies on a form of data storage called data blocks. Unlike hard disks, memory data storage also requires a form of data storage known as paging and segmentation tables.

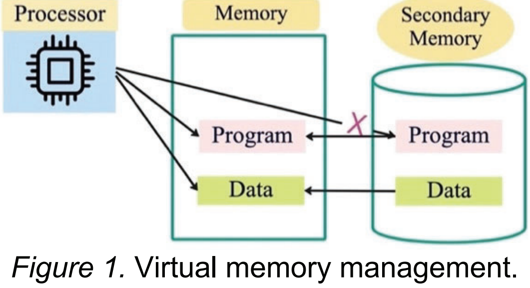

Figure 1. Virtual memory management.

Based on computer structures and data locations, we designed game maps relatively to gamify the above knowledge. Figure 2 represents the corresponding relationship between the data locations and game maps. In Figure 2, the areas where game character movement and game activities occur in the game correspond to the locations where the data storages. For example, the memory map in the game is the memory location where the data storages. Also, the detailed knowledge content required for the different data locations during addressing is matched to the corresponding map. Specifically, bytes are represented by cells in a memory map, and page and segment tables are represented by cell and row tables respectively. In addition, gates are set up between different game maps, and when the character enters the gate of a different map this indicates the corresponding data storage location for reading.

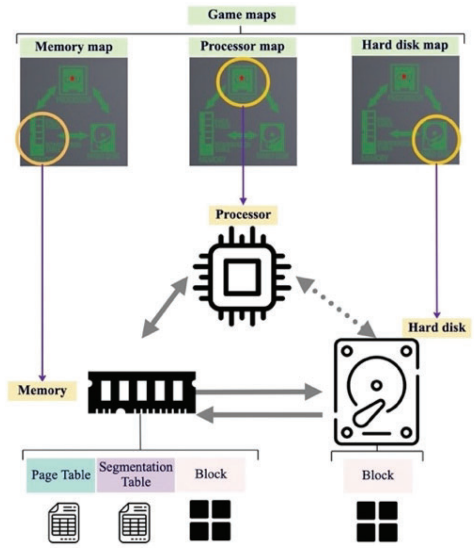

Figure 2. Correspondence between data locations and game maps.

3.1.2 Correspondence between proper nouns and the design of game items

Main challenges in game design come from transforming the proper nouns in OS into the corresponding game items. In Figure 3, the game clues and props are matched to the OS proper nouns. First, game clues. The initial clue of the game is the logical address stored in CPU, since the logical address does not need to be calculated as the initial condition for addressing. The second game clue is obtained by assigning a row in the page or segment table from the logical address, which is represented by a prop box with a clue marker. Secondly, game props. According to the addressing process after the physical address is calculated, the correct block in memory needs to be read. Doors in the game represent the block, and the position of the door indicates the number of blocks. Once inside the door, the character can search for specific data in that block map, represented by a prop box.

Proper nous	Game items in the designed game
Block	Door
Data	Box
Offset	Box location in the block
Logical Address	First clue that firstly obtained at the mission
A Row of Page or Segmentation	Box with a second clue

Figure 3. Correspondence between proper nouns and game items.

3.1.3 Correspondence between addressing operations and game actions

The transformation of proper nouns in OS into game items is based on addressing process, where core information about the operational process in addressing is gamified into game clues and props.

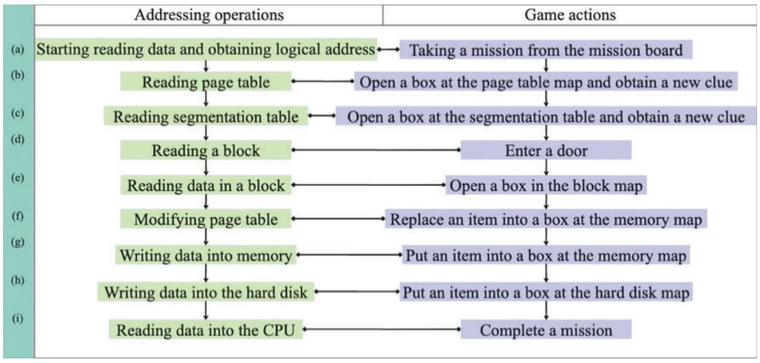

Figure 4. Correspondence between addressing operations and game actions.

The figure 4 shows that the start of addressing operation in the game is represented by the character accepting a task from the task board (a) and obtaining new clues through (b) and (c). Entering the map (e) where data block is stored in prop box through the door (d), finding the corresponding pro box (f) according to the calculation results and completing the storage of the items (g) and (h).

3.2 Learning strategy incorporated in the design of system modules

As shown in Figure 5, three game modules were designed. 1) mission module contained cues to help students understand the sequence of steps in the addressing modes, 2) guide module scaffolds participants with instructions on how to operate the game and learn the task (Yin et al., 2013), and 3) feedback module was responsible for feedback on task status and character position.

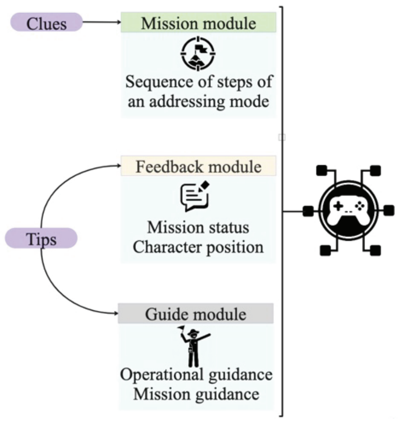

Figure 5. System models.

3.2.1 Game clues in mission module

In the mission model, we gamify six addressing modes and design them into six missions. As shown in Table 1, the six missions correspond to the six addressing modes. In each mission, the game provides the corresponding operational steps for the specific addressing mode. The Figure 6 shows that a specific operation process about mission 1.

First, the participant gets the first clue from the task board, which is the logical address stored in the CPU. Next, participants were given a second clue in the page table prop box, which was to calculate the physical address by reading the page table. In the task, v=1 means that a block of data in memory is read, otherwise it means that a block of data on the hard disk needs to be read. When v=1, the participant calculates the physical address and reads a block of data in memory in the next step. The participant then reads the data in a block based on the calculated offset, while the character opens a box in the block graph. Finally, the CPU gets the data and the game task gets completed.

Table 1. *Six missions about addressing modes*

Mission number	Addressing modes
Mission 1	Obtaining data in memory using page table.
Mission 2	Obtaining data in hard disk using page table without swapping in.
Mission 3	Obtaining data in hard disk using page table with swapping in.
Mission 4	Swapping out data in hard disk.
Mission 5	Obtaining data in hard disk by segment table without error reporting
Mission 6	Obtaining data in hard disk by segment table with error reporting

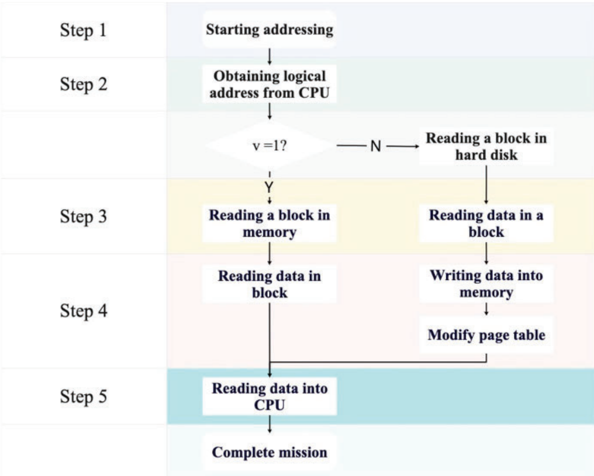

Figure 6. Reading data process in memory by paging.

3.2.2 Tips in feedback module

This module includes game operation and learning mission instruction, as shown in Figure 7. The game operation guidance mainly instructs game participants how to manipulate character behavior, switch between different maps and interact with elements in the map. The learning mission guide can take on the role of an instructor, guiding game participants on how to acquire tasks, showing the meaning and function of game elements, and suggesting solutions for mission completion. Notably, learning missions are designed to provide scaffolding for game participants with timely guidance, which decreases as they progress through the missions and improve their learning abilities. When game participants perform the mission for the first time, they are provided with detailed instructional information. As the number of games increases, the instructional information decreases.

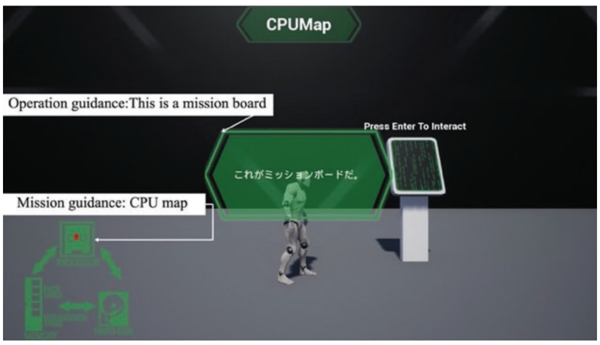

Figure 7. The mission guidance.

3.2.3 Tips in guide module

This module is designed to keep game participants with the mission status, providing information on game location and clues in a timely manner. As shown in Figure 8, the mission location information can help game participants understand the progress changes of the mission and facilitate mastering the current mission. The participant location information, which is a kind of clue information being fed back, can increase the understanding of the game participants on the updated status of the game clues and props.

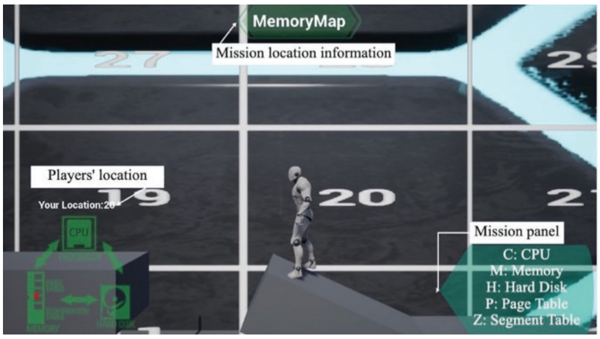

Figure 8. The feedback information.

4. Experiment design

4.1 Participants

An experiment was conducted to verify the contributiveness of the developed game in terms of learning effectiveness and self-efficacy.

A total of 39 participants, from a computer-related discipline at a Japan university, took part in the experiment. The experiment participants were assigned to an experimental and a control group. The participants in the experimental group learned the addressing model using a game-based learning approach, while the participants in the control group completed the learning task by reading the textbook.

4.2 Instruments

The instruments involved in the experiment mainly included measures of learning performance, self-efficacy, and cognitive load. The learning performance measures consisted of pre-test and post-test. The pre-test consisted of 5 multiple-choice and 9 short-answer questions, and its measure was the basics of operating systems. The post-test, on the other hand, consisted of nine comprehensive questions limited to knowledge of the search model. Cognitive load test is a way to examine the impact of a learning strategy on students' learning activities (Zhao et al., 2023). Self-efficacy and cognitive load measures were administered through a questionnaire modified from the questionnaire developed by Pintrich and De Groot (1990).

4.3 Procedure

Figure 9 shows the experiment procedure. Before the learning activity, the experimental and control groups took a 3-minute pre-test and a 10-minute pre-questionnaire, respectively. Subsequently, both of two groups were given a 30-minute learning activity at the same time, in which the experimental group used the designed game to learn the addressing mode, while the control group learned by reading the textbook. Afterward, a 10-minute post-test and a 10-minute post-questionnaire were asked.

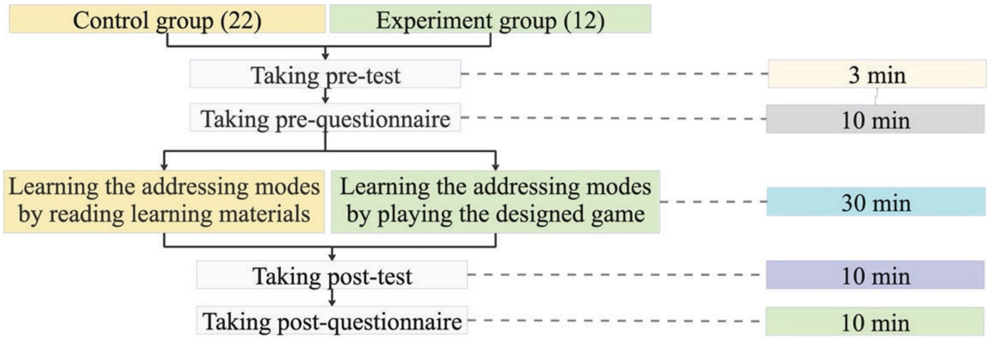

Figure 9. Experiment procedure.

5. Experiment results

After data processing, we obtained valid data for 34 participants. To verify the contribution of the designed game in learning achievement, self-efficacy, and cognitive load. First, a normal distribution test was adopted to analyze three kinds of data using the Shapiro-Wilk test. Specifically, the post-test showed significance (w=0.928, p=0.027), implying that it does not meet the assumption of normality (p<0.05). In addition, pre-test (w=0.980, p=0.775), self-efficacy (w=0.972, p=0.529), and cognitive load (w=0.952, p=0.142) did not present significance (p>0.05), implying that it meets the assumption of normality. So that, a t-test was used to analyze whether there were differences in pre-test, self-efficacy, and cognitive load. Also, the non-parametric Mann-Whitney Test was used to analyze whether there was a difference in post-test.

Table 2. *Descriptive statistics and t-test results of the pre-test*

Variable	Group	N	Mean	S.D.	*t*
Pre-test	Experiment group	22	33.770	6.414	0.607*
	Control group	12	31.420	5.838	

Note. **p* > .05.

The game leaning method on learning performance was examined using the Mann-Whitney test. The table 3 shows that the mean rank of the experimental and control groups were 18.430 and 15.790, respectively, and the sum of ranks were 405.500 and 189.500. Based on Mann-Whitney results (z = -0.751, p>.05) indicate that students in the experimental group who used the game-learning approach to learn addressing model did not differ significantly from the control group students in terms of learning performance.

Table 3. *Descriptive statistics and Mann-Whitney test results of the post-test*

Variable	Group	N	Mean Rank	Sum of Ranks	*z*
Pre-test	Experiment group	22	18.430	405.500	-.751*
	Control group	12	15.790	189.500	

Note. **p* > .05.

The t-test was used to examine the differences in self-efficacy between the experimental and control groups. The table 4 shows that the Mean was 20.41 and 15.33 for the experimental and control groups and the S.D. was 3.763 and 5.416, respectively. The t-test results (t = 3.213, p < .05) show that students in the experimental and control groups were statistically different in terms of self-efficacy. In other words, students who used the game-learning addressing model had higher self-efficacy than had higher self-efficacy.

Table 4. *Descriptive statistics and t-test results of the self-efficacy*

Variable	Group	N	Mean	S.D.	*t*
Pre-test	Experiment group	22	20.41	3.763	3.213*
	Control group	12	15.33	5.416	

Note. *p <.05.

According to table 5 shows that the experimental and control groups in Mean were 23.50 and 21.92, respectively, and the S.D. was 5.570 and 4.680. The statistical results (t = 3.213, p>.05) show that the students in the experimental group with the game-learning addressing mode had similar cognitive load as the students with the traditional approach, which indicates that the game-learning approach did not bring more cognitive stress to control group students.

Table 5. *Descriptive statistics and t-test results of the cognitive load*

Variable	Group	N	Mean	S.D.	*t*
Pre-test	Experiment group	22	23.50	5.570	-.835*
	Control group	12	21.92	4.680	

Note. *p > .05.

6. Conclusions

In the study, a game was developed to solve the low self-efficacy issue of the students in the learning activity by combining the learning content and the game steps with the design concept of game learning. Besides, the game was designed by taking the addressing mode of the operating system course as the learning content in three ways: using the three data locations of hard disk, memory and CPU as the game map; transforming the per nouns such as block, data and offset into one-to-one game elements; converting the operation behaviors in the addressing mode into game operation behaviors Also, the game is designed with three modules that contain learning strategies. They are the mission module, which provides cues; the feedback module, which provides tips; and the guidance module, which has a similar functions with giving tips.

To examine whether the developed game can solve the problem of low self-efficacy exhibited by the students in the learning activities, a comparison experiment was conducted. Based on the results of the experiment in three dimensions: learning achievement, self-efficacy, and cognitive load, the game was statistically analyzed for avoiding low self-efficacy behavior. First, according to the results of the t-test, the students in the experimental group who used game learning, did not differ significantly from the students in the control group who used traditional learning in terms of learning achievement. Second, with similar learning achievement, students in the experimental group differed significantly from students in the control group in terms of self-efficacy, and students in the experimental group had higher self-efficacy, which implied that the developed game could improve self-efficacy. In addition, T test was adopted to test whether the introduction of the game learning method brought about cognitive load on students. Based on the results showed that there was no significant difference between the experimental and control groups in terms of cognitive load. This indicates that the game-based learning strategy did not bring about additional cognitive load.

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