Effects of Different Cognitive Load Courses in Game-Based Learning on Students' Visual Attention and Learning Performance

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Abstract

Cognitive load is a critical factor affecting the learning performance of students. Previous studies have indicated the effectiveness of educational computer games for learning. However, there is little study on what effects of different cognitive load courses in game-based learning on students' visual attention and learning performance. This study was to investigate elementary school students' visual attention and learning performance using an educational computer game with different cognitive load courses. The subjects included students of fifth and sixth graders of an elementary school. One group was assigned to play the game of low cognitive load and the others were assigned to play the game of high cognitive load. Students whose visual attentions were recorded by the eye tracking system while playing the educational computer games. Content analyses were examined individual's Hot Zone image, fixation count and total fixation duration to indicate their attention. The experimental results show the high cognitive load group displayed the higher fixation count and total fixation duration to the text zones than low cognitive load group. The results also show the high cognitive load group had better learning achievements than low cognitive load group.
Keywords: *Cognitive load, Educational computer game, Interactive learning environments*

1. Introduction

Educational computer games have also been recognized as a popular trend in learning (Garris, Ahlers, & Driskell, 2002; Hwang & Wu, 2012). Previous studies have reported that educational computer games can enhance the learning interest of students (Ebner & Holzinger, 2007; Malone,1980), and further increase their learning motivation (Burguillo, 2010; Dickey, 2010; Harris & Reid, 2005; Miller, Chang, Wang, Beier & Klisch, 2011). In the past decade, previous studies have indicated the effectiveness of educational computer games for learning, such as mathematics (Chang, Wu, Weng & Sung, 2012; Lowrie & Jorgensen, 2011), computer science (Cagiltay, 2007; Papastergiou, 2009) and geography (Tüzün, Y.lmaz-Soylu, Karakus, Inal,& K.z.lkaya, 2009). However, there is little study on what effects of different cognitive load courses in game-based learning on students' visual attention and learning performance. However, Intrinsic cognitive load is an interaction between the nature of the material being learned and the expertise of the learners, which cannot be directly influenced by instructional manipulations (Paas & Kester, 2006). Thus this paper aims to investigate elementary school students' visual attention and learning performance using an educational computer game with different cognitive load courses, only intrinsic load were affected in the present study.

Based on the eye-mind assumption that eye fixation locations reflect attention distributions (Yang, Chang, Chien, Chien, & Tseng, 2013; Just & Carpenter, 1980), the eye tracking method can reveal the temporal change of visual attention that may further inform how learners approach and process information during learning. In general, eye fixation duration reflects processing difficulty and amount of attention and eye fixation location reflects attention. Therefore, we are particularly interested to use eye tracking method in game-based learning. To probe in-depth into how students learn concepts in the educational computer game with different cognitive load courses, we conducted a study that examined students' visual attention in terms of their eye-movement patterns as they were given an educational computer game.

2. Literature review

2.1. Cognitive load

Cognitive load refers to the informational load that is being processed in working memory (Van, Paas, & Sweller, 2010). Cognitive load theory explains that there is a certain amount of information that can be processed in working memory at one time without overloading processing capacity. Thus, when cognitive load is increased beyond our working memory capacity, learning is depressed (Pastore, 2012).

There are three types of cognitive load: intrinsic, extraneous and germane (Sweller, 2010 ; Chang, Tseng, & Tseng, 2011). Intrinsic cognitive load is an interaction between the nature of the material being learned and the expertise of the learners, which cannot be directly influenced by instructional manipulations (Paas & Kester, 2006). Extraneous load happens when a learner engages in a cognitive processing that does not support the learning objective, such as poor layout, whereas germane load occurs when a learner engages in a deep cognitive processing that mentally organizes the material and relates it to prior knowledge, meaning that a learner's motivation and prior knowledge are enhanced and connected with prompts and supports in the lesson

(DeLeeuw & Mayer, 2008). Due to intrinsic cognitive load is inherent to the task complexity. In the experiment described in this paper, intrinsic s load is being manipulated with different cognitive load courses.

2.2. Educational computer game

Kinzie and Joseph (2008) indicated that "a game is an immersive, voluntary and enjoyable activity in which a challenging goal is pursued according to agreed-upon rules." Owing to the rapid advancement and popularity of computer and communication technologies, researchers have predicted that more technology-based learning will occur, and educational computer games could play an important role in education (Prensky, 2001). In the past decade, many studies have been conducted to investigate the effectiveness of educational computer games for various courses, such as mathematics(Chang et al. 2012; Lowrie & Jorgensen, 2011), natural science (Hwang, Wu, & Chen, 2012), Science (Meluso, Zheng, Spires, & Lester, 2012), computer science (Papastergiou, 2009), social science (Cuenca López & Martín Cáceres, 2010), geography (Tüzün et al., 2009), language (Liu & Chu, 2010) and decision-science (Chang, Peng, & Chao, 2010). Researchers have indicated the potential of employing educational computer games in helping students improve their learning performance (Brom, Preuss, & Klement, 2011; Huang, Huang, & Tschopp, 2010; Wang & Chen, 2010). For example, some studies have indicated that digital games are an important part of the development of children's cognition and social processes (Kim, Park, & Baek, 2009; Yien, Hung, Hwang, & Lin, 2011).

In the context of changing world, instructional designers and teachers have increasingly embraced students' interest in digital games, as well as the design advantages provided by modern computing. Games are a very rich interactive medium for enhancing the fun factor of the learning experience, and allow the players to explore the rules of the game world by trial and error (Moreno-Ger, Burgos, Martinez-Ortiz, Sierra, & Fernandez-Manjon, 2008; Torrente, Lavín-Mera, Moreno-Ger, & Fernández-Manjón, 2009). By means of digital games, and especially of digital educational games, learners should be able to apply factual knowledge, learn on demand, and gain experience in the virtual world, all of which can later shape their behavioral patterns and directly influence their reflection (Pivec, 2007). Many educational game designers also advocate developing simpler games at a more reasonable cost in contrast to commercial off-the-shelf games. Researchers have indicated that those educational games with simpler interfaces could be more beneficial to learners owing to the lower requirements for technical skills (Torrente et al., 2009). Such a viewpoint conforms to the need for developing spatial learning tools with a game-based approach since the learners are elementary school students (Hung, Hwang, Lee, & Su, 2012). Many research have reported that educational computer games can enhance the learning interest of students (Ebner & Holzinger, 2007; Malone,1980), and further increase their learning motivation (Burguillo, 2010; Dickey, 2010; Harris & Reid, 2005; Miller et al., 2011).

3. Method

3.1. Participants

The participants of this study were grade 5 to 6 elementary school students. A total of twenty-one students voluntarily participated in the study. One group was assigned to play the game of low cognitive load and the others were assigned to play the game of high cognitive load. The low cognitive load group, including ten students, was guided by the educational computer game that teaching materials with geography, while the high cognitive load group with eleven students was guided by the educational computer game that teaching materials with mathematics. All participants passed the eye-tracking calibrations. Students whose visual attentions were recorded by the eye tracking system while playing the educational computer games.

Fig. 1. The shooting games let the participants try to avoid the enemy's attack and try to return fire the correct answer at the same time.

3.2. Materials

Two same shooting- games was prepared for the study. The gameplay of shooting-game is that players try to avoid the enemy's attack and try to return fire at the same time (see Fig. 1). Shooting- games consisted of 6 minutes learning materials on the topic of "mathematics" and "geography". "Mathematics" which is about positive number and negative number and "geography" which is about France, Germany, Italy and Spain's culture and architecture. This educational computer games has three part, the first part gives the practice of the lesson. The second part contains one or two slides of learning materials. The last part let the participants try to avoid the enemy's attack and try to return fire the correct answer at the same time. The content and the design of the educational computer games presentation were constructed a mathematics and geography education researcher. We ensured that the learning materials used in the educational computer games that the participating students might have read prior to the study.

3.3. Apparatus

This study employed the i-Seizer Lite Version eye tracking system developed by Utechzone Co., Ltd., which is a fully automated eye tracking system. The system consists of one desktop computer and one i-Seizer Eye Tracker. It is able to provide eye movements data. The average sampling rate of i-Seizer Eye Tracker is 60 Hz, that is, 60 eye-movement samples are captured in one second. A 17-inch flat panel monitor with a resolution of 1280x1024 was used to display the educational computer game to the participants. Participants played the game using a mouse. i-Seizer Lite Version eye tracking system installed in the desktop computer was used to store and analyze the gaze data.

3.4. Procedure

At the beginning of the learning activity, the students took the pre-test. During the learning activity, one group was assigned to play the game of low cognitive load and the others were assigned to play the game of high cognitive load. The eye tracker was then placed on a table in front of the subject about 60 cm away. Each participating student went through a calibration process for the eye tracker to capture the correct positions of the student's eye movements. The educational computer games took about 9 min to complete. During the games, recording system was utilized for the researcher to examine the students' eye movements. This system overlaid both the educational computer games on a computer screen and the students' eye movements. After the learning activity, the students took the post-test.

3.5. Data analysis

For the purpose of examining the Participants' attention distributions on the different components of the educational computer games, each game part was divided into several 'Region of Interest' text zones consisting of learning materials. To summarize the eye movement patterns on each game part, eye-movement measures including total fixation duration and fixation count were used. Total fixation duration represent sum of durations of all fixation points on a 'Region of Interest', and fixation count represent sum of number of all fixation points on a 'Region of Interest'. An observation on individual Hot Zone map was conducted for exploring participants' attention. The eye-movement data were exported to Excel, and SPSS was then applied for further statistical analyses.

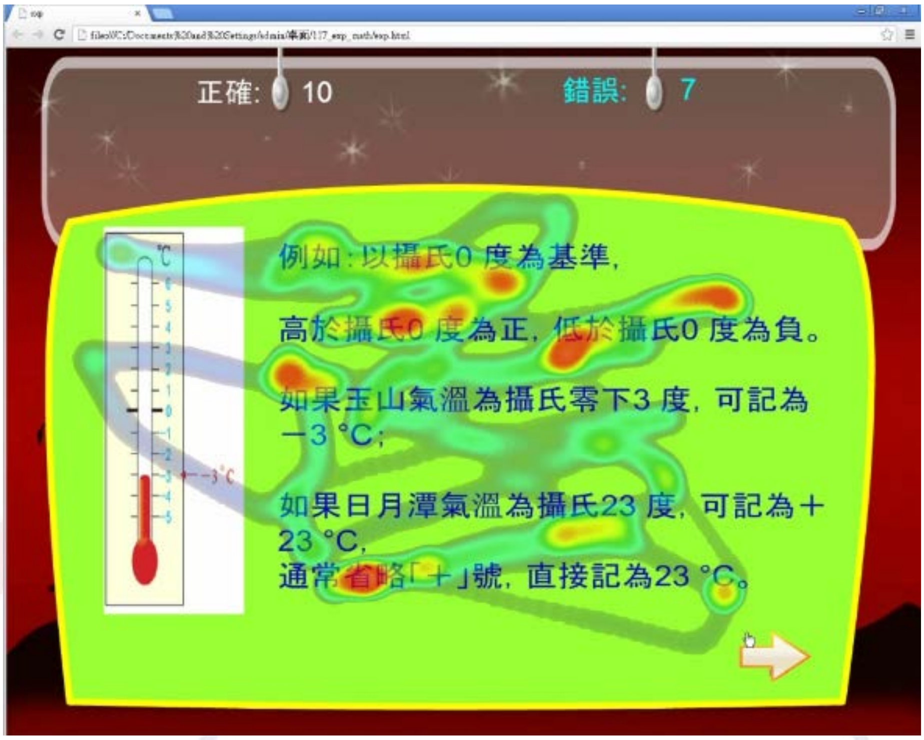

Fig. 2. As the graphics show, Students were focus on the 'Region of Interest' in the learning materials on the topic of "mathematics".

4. Results

4.1. Heat Map

In order to describe an entire screen of a participant's visual attention on the educational computer games, we analyzed the Heat Map. In the Heat Map, the mapped color varied from individuals' total fixation duration on the screen. The red or orange spots represented locations where the participants had been accumulated longer total fixation duration while blue colors represented locations where the participants had been accumulated shorter total fixation duration. In the educational computer games, most of the students paid most attention to 'Region of Interest' consisting of learning materials. Figs. 2 and Figs. 3 show the result.

It shows students are able to focus on the learning objectives and attraction of the game. However, an accumulated amount of attention on a particular area seems not enough for understanding different cognitive load courses in educational computer games. Therefore, total fixation duration and fixation count on the 'Region of Interest' was further conducted to show the visual attention by participants in different cognitive load courses groups.

Fig. 3. Comparison of eye movement patterns on the 'Region of Interest' between learning materials and play zone. As the graphics show, the fixation densities of the students were higher on 'Region of Interest' learning materials.

4.2. ANOVA with different cognitive load courses

To investigate whether participants had difference in the different cognitive load courses, we conducted three parts of educational computer games ANOVA with participants' fixation duration and fixation count on 'Region of Interest' learning materials. The results of measures analysis on fixation durations are shown in Table 1. For three parts of educational computer games, significant differences were found in the first part of games also fixation duration and fixation count, but there were no differences in the second part and the last part of games.

Table 1

ANOVA with different cognitive load courses

Game parts	Variables	VS	SS	Df	MS	F	p
First part	fixation count	Between	11092.57	1	11092.57	14.64	.001
		Within	14395.24	19	757.644		
Second part		Between	1342.48	1	1342.48	.312	.583
		Within	81771.801	19	4303.78		
Last part		Between	7391.09	1	7391.09	.424	.523
		Within	331068.15	19	17424.64		
First part	fixation duration	Between	585.19	1	585.19	9.402	.006
		Within	1182.54	19	62.24		
Second part		Between	282.39	1	282.39	.953	.341
		Within	5628.98	19	296.26		
Last part		Between	179.19	1	179.19	.261	.615
		Within	13046.77	19	686.67		

4.2 Visual attention distributions for different 'Region of Interest'

To further examine students' visual attention in our games, two paired t-tests were conducted to compare the fixation duration and fixation count in the last game part between 'Region of Interest' learning materials and 'Region of Interest' play zone. Regarding fixation duration, the paired t-test on fixation durations between 'Region of Interest' play zone (M = 267.1 s, SD = 139.23) and 'Region of Interest' learning materials (M = 109.49 s, SD = 25.72) show significant difference (t = 4.983, df = 20, p = .000), while the paired t-test on fixation count between 'Region of Interest' learning materials (M = 404.48, SD = 130.09) and 'Region of Interest' play zone (M = 92.89, SD = 50.82) also show significant difference (t = 8.386, df = 20, p = .000). Despite on fixation duration, play zone show significant difference with learning materials. Fixation count learning materials show significant difference with play zone. This phenomenon is due to the design of the game that participants see the questions and try to return fire the correct answer at the same time. Therefore, the results seemed to support students allocated much of their attention to learning materials.

4.3 Analysis of learning achievement

One of the objectives of this study was to examine the effectiveness of the educational computer games in terms of improving the learning achievement of the students. ANCOVA was used to examine the difference between the post-test scores as dependent variables and the pre-test scores as the covariate. The homogeneity test result showed that the post-test scores of the two groups were homogeneous (F = 0.33, p = 0.86 > 0.05), implying that ANCOVA could be applied. Table 2 summarizes the ANCOVA results, in which the adjusted mean values of the post-test scores were 72.73 for the high cognitive load group, and 53 for the low cognitive load group.

Table 2
Descriptive data and ANCOVA of the post-test results.

Group	N	Mean	S.D.	Adjusted mean	Std. error	F	p
high cognitive load group	11	72.73	25.08	71.82	6.41	3.469	.079
low cognitive load group	10	53.00	20.66	54.00	6.74		

5. Discussion and conclusions

In this study, we used the eye tracker to record and analyze learners' visual attention distributions over the educational computer games. Our study showed that during playing the games, the students allocated much of their attention to learning materials. When playing the educational computer games, visual attention increased for 'Region of Interest' text zones consisting of learning materials, compared to 'Region of Interest' play zone. Although in the Heat Map there was no difference of the pictures between the different groups, further analyses of the fixation count and total fixation duration revealed that the high cognitive load group displayed the higher attention to the text zones than low cognitive load group. Finally, the post-test showed the high cognitive load group had better learning achievements than low cognitive load group.

In sum, this study explored students' visual attention during a educational computer games on different cognitive load courses. The findings of attention allocations help instructional designers and teachers to understand students' potential misconceptions or difficulties in different cognitive load courses and further design suitable educational computer games. As educators, our primary aim is to study students' learning processes by using eye tracking system. Therefore, future studies may apply eye tracking system to explore the cognitive process of different cognitive load courses and investigate the potential and limitation of its applications in future educational computer games. More communication is needed among technology developers, eye tracking system researchers, and educators to carry out such an implementation.

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