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Effects of Different Advance Organizers on Mental Model Construction and Cognitive Load Decrease

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The purpose of this study was to investigate why advance organizers (AO) are effective in promoting comprehension and mental model formation in terms of cognitive load. Two experimental groups: a concept-map AO group and a key-word AO group and one control group were used. This study considered cognitive load in view of Baddeley's working memory model: central executive (CE), phonological loop (PL), and visuo-spatial sketch pad (VSSP). The present experiment directly examined cognitive load using dual task methodology. The results were as follows: central executive (CE) suppression task achievement for the concept map AO group was higher than the key word AO group and control group. Comprehension and mental model construction for the concept map AO group were higher than the other groups. These results indicated that the superiority of concept map AO owing to CE load decrement occurred with comprehension and mental model construction in learning. Thus, the available resources produced by CE load reduction may have been invested for comprehension and mental model construction of learning contents.

Keywords : advance organizers, working memory, cognitive load, dual task methodology

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Introduction

All learning experiences should be meaningful to students in face-to-face classrooms and e-learning environments. One way to make learning meaningful is to provide the learner with background information related to the up-coming learning topic in advance, especially when he or she does not have relevant prior experience and knowledge of the learning content. Specific advance information is able to facilitate schema construction in long-term memory.

Although many studies have been performed on the effectiveness of Advance Organizers (AO) types, there is still a lack of understanding regarding how and why AOs are effective (Duke & Rinck, 2006, Langan-Fox, et al., 2006, Sutherland, et al., 2003). If an AO improves achievement, what's the reason for this? Previous AO studies (Larkin & Simon, 1987; Robinson & Kiewra, 1995; Langan-Fox, et al., 2000) revealed the superiority of graphic AOs compare to linear AOs. Graphic AO, the construction of which is based on a spatial arrangement of words to convey concept relations, has a format that may be more appealing than that of linear organizers. Graphic AO supports efficient computational processes (Robinson & Skinner, 1996), promotes elaborative processing and decreases memory load (Baddeley, 1986, 1998, 2001). However, previous studies didn't explain why graphic AO is more efficient than linear AO, nor did they measure the decrease of cognitive load according to AO type. A single test was used to investigate AO effects (Oh & Kim, 2006), it's only a short-term effect. The results cannot explain how an AO affects the connection between new knowledge and prior knowledge in long-term memory. Therefore, this study implemented immediate and delayed mental model formation tests to confirm the effect of an AO in long-term memory.

The purpose of this study is to investigate AO effect in terms of cognitive load. In order to find the answers to these questions, the present experiment examines cognitive load in a dual task situation after students learned the concept map AO as a graphic AO and the key word AO as a linear AO.

AO Type and Learning Achievement

Many empirical studies have examined the effect of providing advance information to the to-be-learned topic in terms of memory and knowledge acquisition (Asubel, 1960; Mayer, 1978, 1979a, 1979b, 1983, 1989; Rawson & Kintsch, 2002; Schwartz et al., 1998, Sutherland et al., 2003). In relation between achievement and cognitive load according to AO types, it was predicted that there was no significant difference in retention among groups. It was inferred that no particular learning strategies are needed because retention tasks demand a small amount of working memory resources. Therefore, the AO type didn't affect the retention scores. However, it was predicted that there would be a significant difference in comprehension among groups. Comprehension tasks need more resources than retention tasks. AO-provided groups were able to prepare schema construction prior to learning therefore, they needed less working memory resources than the control group. Comprehension of the concept map AO group should be higher than the key word AO group because a key word AO requires more resources in inferring meaning and concept relationships than a concept map AO.

Mental model is the representation that integrates propositions from the text base with pictorial elements from the visual image into a new, coherent structure representing the entities (Duke & Rinck, 2006). It means learning is beyond comprehending the text itself and it is an understanding of the situation described by the text (Chi & Kim, 2004; McNamara, et al., 1996; Kintsch, 1986, 1993). That is, learners are coming to integrate AO with learning materials and reorganizing their own knowledge structures in long-term memory. These integrations and organizations are assumed to require working memory resources. Concept map AO would better facilitate mental model formation than key word AO because of its computational efficiency (Larkin & Simon, 1987). Is it possible that a certain AO type can reduce the cognitive load? To examine this point, this study used dual task methodology to measure cognitive load.

Advance Organizers and Cognitive Load

Cognitive load is based on several assumptions of human cognitive architecture: unlimited capacity of long-term memory, schema theory of mental representation, and limited capacity of working memory. Working memory is consisted of a multi-component model: phonological loop (PL), visuospatial sketchpad (VSSP) and central executive (CE) (Baddeley, 1986, 1998, 2001, 2006). The central executive was envisioned as a control system of limited attention capacity that is responsible for the manipulation of information within working memory and for controlling the two subsidiary storage systems: the phonological loop and the visuospatial sketchpad. The phonological loop was assumed to be responsible for the storage and maintenance of information in a phonological form, while the visuospatial sketchpad was dedicated to the storage and maintenance of information in a visual and spatial form. Cognitive load is determined as the loads of the three working memory subcomponents.

Although cognitive load theory has provided theoretical background in multimedia learning and web-base learning (Mayer & Moreno, 1998, 2000, 2003; Moreno & Mayer, 2000, 2003; Merrienboer et al, 2002: Merrienboer & Sweller, 2005; Sweller, 1988, 1994; Sweller et al., 1998), these studies didn't directly assess actual cognitive load (Brunken, et al, 2002, 2003). In particular, they ignored the role of CE in multimedia learning (Sutherland, et al., 2003). Relatively few studies have examined the working memory load: PL, VSSP, and CE in multimedia learning and web-based learning. (Oh & Kim, 2003; Jin & Oh, 2003; Oh & Jin, 2004; Oh & Kim, 2006).

The present study was to directly evaluate working memory load using dual-task methodology. The method is based on the assumption that the processing capacity of working memory is limited but can be flexibly allocated (Baddeley, 1986, 1998, 1999; Miyake et al., 2000). If two tasks have to be processed at the same time, cognitive resources have to be shared between the two tasks. This means that fewer resources are available for processing each individual task than would be available for processing a single-task. Because students would be attempting to perform two tasks at the same time, it's likely that one task might interfere with performance on the other task (Baddeley, 1986, 1998; Furst & Hitch, 2000; Robinson et al., 1999; Whitney, et al., 2001). In this experiment, subjects had to process primary learning tasks while secondary tasks suppressed working memory sub-components.

In a dual task situation, if the concept map AO was presented prior to target learning, students could easily compose the concepts' relation and hierarchy about the up-coming learning topic. Students who were provided a concept map AO would experience less load in solving primary learning tasks and secondary tasks simultaneously than other groups. It is predicted that the concept map which has an efficient computational process (Robinson & Skinner, 1996) would decrease cognitive load. Therefore, subjects would get higher scores in the primary learning task as well as the secondary task because of the decline of cognitive load resulted from the nature of concept map AO.

Method

Participants

In order to test these hypotheses, fifty-four participants who were undergraduates in C University teachers' college participated in this study. Students were randomly assigned to one of the three groups: a concept map AO group, a keyword AO group, and a control group. All participants took a pretest for prior knowledge and a post-test which comprised of retention, comprehension and mental model formation tests. Two students' data were eliminated from the study because the result of working memory test had errors. Finally the concept map AO group was comprised of 16 participants, the keyword AO group was comprised of 20 participants, and the control group was comprised of 14 participants.

Instruments

Pre-test materials

The pretest for prior knowledge consisted of 20 questions about the content domain. After the test was developed by two subject experts (a doctor and a biology teacher), the study conducted a pilot test to obtain validation. Then, the awkward sentences of the test were amended. The test was administered as a paper-pencil test.

Post-test materials

Performance was assessed by using a test with 35 items including tasks for retention, comprehension, and mental model formation. The retention items included simply memorized and recalled factual knowledge. The retention tests were made up of 20 multiple-choice items. The comprehension tests consisted of items, which were beyond the just-memorized factual knowledge. These items required the interpretation of factual knowledge and inference of an unknown fact from a known fact. The comprehension test was designed as a 15-item multiple-choice test.

Mental model is an internal representation of objects, actions, situations to people and is built on experience and observation (Cook, 2006; deSessa, 1993, Langan-Fox, et. al., 2004). To measure a mental model, subjects were asked to draw a concept map to represent concept relationships in the learning tasks as best as they could after the learning program. The concept map has widely been used to measure quality and quantity of learning achievement. We developed the framework of evaluation criterion using previous studies (Kim, 2002; Chi & Kim, 2004; Liu, 2004; Novak, 1998; Novak & Gowin, 1984; Mason, 1992; Rye & Rubba, 2002). Our concept map scoring criteria was as follows: the number of concepts, the accuracy of their relationships, and the cross-links and concept hierarchies. 2 raters, subject-matter-expert assessed students' concept map comparing to expert concept map.

Learning program

Learning program was made as a web-based instruction (WBI) program and consisted of two steps: an AO-learning step and a task performing step. Firstly, in the AO-learning step, while the concept map AO group was provided with a concept map (fig. 1) about diabetes for 5 minutes before the task performing, the key word AO group was provided with a word list (fig. 2) concerning diabetes for 5 minutes. Although both experiment groups were different in form, they equivalently had the number of 25 concepts due to consideration about fair information amounts. However, the control group's learning program did not contain a step for AO-learning.

Figure 1. Concept map of concept map AO

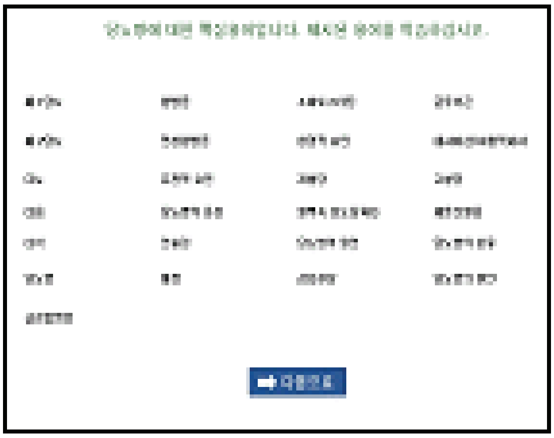

Figure 2. A word list of keyword AO

Secondly, the task performing step had a total of 42 task sessions, and a task session consisted of a combination of a primary task and a secondary task like figure 3, that is, a problem question pertaining to the secondary task, a reading task pertaining to the primary task and answering the secondary task problem question. Primary tasks were reading materials on diabetes and secondary tasks were working memory suppression tasks to measure cognitive load. When students learn the primary task, they also have to hold the working memory suppression task simultaneously because they need to answer the secondary task problem question at the end of the task.

Screen 1.
Question on secondary task

Screen 2.
Primary task

Screen 3.
Answer on secondary task

Figure 3. A session sample in learning program

The primary tasks focused on diabetes and the contents contained five categorized areas such as causes, symptoms, complications, types of diabetes, and the pancreas which is an important internal organ related to diabetes. This theme was very unfamiliar to the subjects, so it was a very appropriate learning task to investigate the effectiveness of AO types in respect to cognitive load. Primary task screens were kept for at the least 15 seconds and were automatically changed to the next screen after 15 seconds.

The secondary tasks were designed for working memory suppression, with the purpose of measuring cognitive load because the secondary task is added to the primary task in hopes of inducing memory load. Subjects had to process both primary tasks which contain contents of diabetes and secondary tasks which were to suppress working memory subcomponents: CE, PL and VSSP. The CE working memory suppression task was a modification of letter memory task used in the studies of Morris & Jones (1990) and Miyake et al. (2000). These memory updating tasks which were used in the CE working memory load task need the CE resource to learn a primary task. Instead of the letter memory task, a number memory task randomly presented a number from 0 to 9 every second on a computer monitor. The experimenter explained to the subject that the length of a given number set might be six, eight or ten digits and the ordering of these lists was random. They were also told that they should recall only the last four numbers presented. Students had to choose an answer within 3 seconds. The PL working memory load task was a modified task used in the study of Robinson et al. (1999, 2002). Unlike the Robinson study that used numbers, this experiment presented five different Korean language consonants in the central location of a computer monitor for 3 seconds. The subjects had to identify the same consonant list in multiple choice items. The VSSP working memory load task was similar to those used in the experiment of Robinson et al. (1996, 1999, 2002). It consisted of a rectangle grid, nine cells by nine cells, and five solid black dots. First, a configuration screen was presented for 3 seconds. In the next screen, subjects had to select the same configuration among four choices.

The learning program was developed on PHP language for the Windows XP operating system by a researcher and a programmer. The content validity of the program was checked by two subject matter experts (a doctor and a teacher of biology). Also, to improve the reliability and validity of the experiment, a pilot test was administered to 12 students who didn't attend the experiment.

Procedure

In a forty-five minute e-learning class offered a week prior to the experiment, subjects learned what concept maps are and how to draw them. Also, they had to perform and submit an assignment about concept maps to confirm whether they understood concept maps or not. After confirming the assignments, researchers in the study gave an extra lesson to students who did not understand concept maps. Then, in the experiment, participants first completed a pretest which assessed their prior knowledge concerning the content domain for 10 minutes. After finishing the pretest, the experimenter guided participants on how to operate the learning program and provided a practice session for about 10 minutes on how to operate the computer program properly. Then, subjects had to enter a personal ID and began the learning program. In the learning task, two experimental groups performed AO-learning in the first step for 5 minutes. Next, they did task performing which consisted of 42 sessions that combined the primary tasks and the secondary tasks. Students were told that they would be attempting to do two things at once and that they should try to do their best at both tasks. Participants learned contents on diabetes while undertaking one of the interference tasks targeting working memory subcomponents. To prevent memory effect of presentation sequence, the working memory load tasks: CE, PL, and VSSP working memory load tasks were randomly presented. The second step took about 30 minutes for subjects to complete.

After the learning program was finished, subjects took a break for 5 minutes. Then, they started a paper-pencil post-test: retention, comprehension, and mental model test. Retention and comprehension tests consisted of multiple choice items and the mental model test required participants to draw a concept map. After one week, students had to draw a concept map on diabetes again to measure whether AO affected forming a mental model or not.

Data Analysis

The study used ANCOVA to test achievement on the primary tasks (retention, comprehension, and mental model) among the three groups according to AO type. Prior knowledge was disposed by covariance*,* AO types were independent variables and learning task scores were dependent variables. For the display between-subjects effect, results of a Levene's test supported the homogeneity of variance assumption ($\alpha > .05$). ANOVA was used to analyze the working memory load task according to the AO type. In addition, repeated measures of ANOVA were used to analyze the difference between immediate and delayed mental model formation scores. All statistical tests were conducted at the level of significance of $\alpha = .05$.

Results

AO types and learning achievement

Table 1 presents the means and standard deviations for scores on retention and comprehension tasks by AO type. There was no significant difference in retention scores between AO types ($F_{2, 48} = 1.523$, $p > .05$).

Table 1. Mean score on learning achievement by AO type

Group	N	Retention (max: 20)		Comprehension (max: 15)	
		M	SD	M	SD
Concept map AO	16	16.74	.60	12.89	.57
Key word AO	19	15.37	.43	11.14	.41
Control	17	15.66	.51	9.36	.49

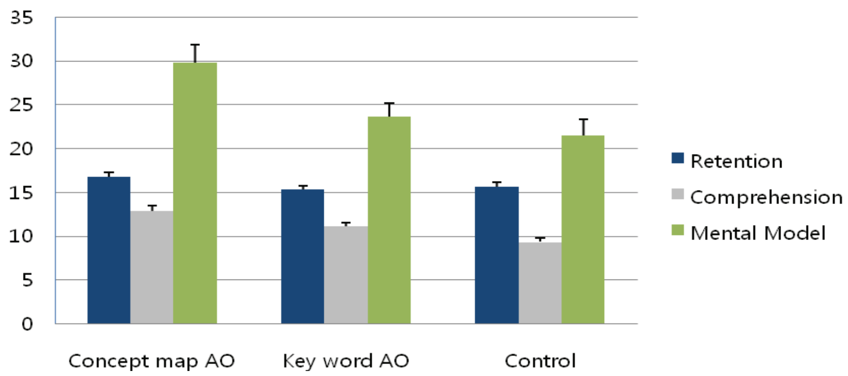

Figure 4. Learning achievement sub-component comparison

However, comprehension achievement among groups had a significant difference ($F_{2, 48}$=8.712, $p<.05$). Participants who received AO scored higher on the comprehension test than the control group. The post hoc Tukey tests showed the differences between the concept map AO group and the keyword AO group and between the keyword AO group and the control group.

Mental model tests score by AO type

Also, Table 2 shows means and standard deviations for scores on mental model tasks according to AO type. In the immediate mental model test, participants who were in the concept map AO group acquired higher scores than the keyword AO group and the control group. ANCOVA revealed a significant difference among the groups ($F_{2, 48}$=3.428, p<.05). The post hoc Tukey tests showed the differences between the concept map AO group and the keyword AO group, the concept map AO group and the control group. Performance of mental model formation for the concept map AO group was more highly maintained than the key word AO group and the control group.

Repeated measures ANOVA were used to analyze the difference between the immediate and delayed tests on the formation of mental model. The results of repeated measures ANOVA revealed that there was a significant statistical differences ($F_{1, 49}$=9.827, p<.05). Performance of mental model formation for the concept map AO group was more highly maintained than the key word AO group and the control group.

Table 2. Descriptive statistics of mental model according to time interval

Group	N	Immediate M M S*				Delayed M MS			
		M	SD	Corrected Average	SE	M	SD	Corrected Average	SE
Concept map AO	16	31.00	6.36	29.79	2.12	29.44	5.48	28.69	2.16
Key word AO	19	23.37	6.69	23.67	1.50	20.37	8.02	20.55	1.52
Control	17	20.65	5.93	21.50	1.81	17.41	5.08	17.91	1.84
Total	52	24.83	7.57			22.19	8.06		

* Mental Model Scores

AO types and cognitive load

Table 3 and Fig. 5 present means and standard deviations for scores on working memory load (WML) tasks by AO type. The mean of CE WML tasks on the concept map AO group was higher than the other groups. A one-way ANOVA of CE WML tasks on AO type revealed a significant difference ($F_{2, 49}$=5.477, p<.05).

The post hoc Tukey tests showed the differences between the concept map AO group and the keyword AO group and the control group. As Table 3 depicted, the mean of PL and VSSP tasks for the concept map AO group was higher than the other two groups. However, there was no significant difference among the groups ($p > .05$).

Table 3. Mean score on WML sub-component

C	N	CE (max:15)		PL (max: 13)		VSSP (max: 14)	
		M	SD	M	SD	M	SD
Concept map AO	16	14.31	1.08	10.88	1.89	13.06	1.39
Key word AO	19	12.05	2.90	9.11	2.64	12.37	1.61
Control	17	13.18	1.38	9.59	2.60	12.53	1.38

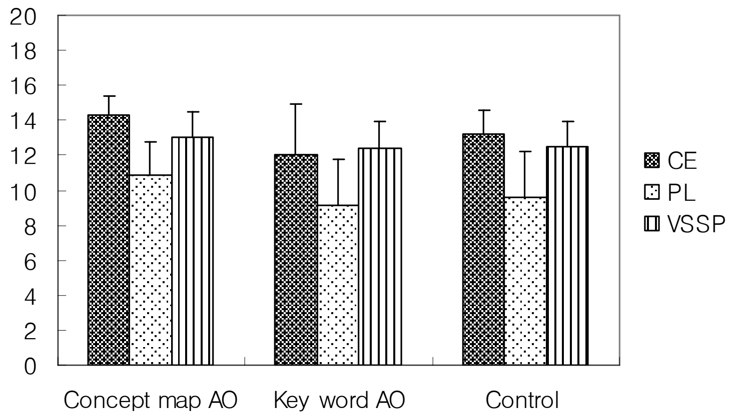

Figure 5. WML sub-component comparison

Discussion

The purpose of this study was to investigated the advantages of graphic AOs compared to linear AOs with respect to cognitive load. In general, AO presented before the target learning material significantly facilitated integration of the experience into a general knowledge representation. To define the reason why AO could help learning, the present experiment consider between learning achievement and working memory load: CE, PL, and VSSP in dual-task situations.

Firstly, in the retention and comprehension scores of learning tasks in dual-task condition, there was no significant difference in retention corresponding to AO type. These results were in accord with our prediction because retention tasks were simple. It has been concluded that retention tasks do not require heavy resources. However, there were a significant differences among AO types with respect to comprehension scores. The comprehension achievement of AO groups outperformed than the control group. Especially, comprehension achievement of the graphic AO group was higher than the linear AO group. These results verified the prediction that the advantage of the concept map should facilitate comprehension. Secondly, there was a significant difference among groups with respect to comprehension scores. The difference was between the concept map AO group and other two groups: the keyword AO group and the control group. After one week, the delayed mental model test also showed the effect of a concept map AO. The results showed that the concept map AO group organized knowledge structure in long-term memory better than the other groups. The difference in concept mapping by time intervals justified that the concept map AO could prevent forgetting in memory. It can be inferred that the concept map AO improves comprehension of text content and organization of schema construction in long-term memory.

Thirdly, memory load task achievement in undertaking the primary learning task was measured according to the AO type. The results showed CE working memory load task achievement of the concept map AO group was significantly higher than the other groups. What was interesting is that CE load task achievement for the key word AO group was lower than the control group though there was not a significant difference. In actuality, the key word AO group acquired higher achievement than the control group in the primary learning tasks (comprehension, mental model formation). However, the secondary task scores of the key word AO group were lower than the control group. This means that in dual task situation, the key word AO group experienced more cognitive load than the control group. In conclusion, the nature of the concept map AO could decrease cognitive load on the CE and available CE resources could be invested towards comprehension and mental model formation. These results can also be interpreted as indication that the nature of graphic AO facilitates schema construction and helps overcome working memory limit capacity, especially for the CE.

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