Effects of Cognitive Load Reduction Strategies and Prior Knowledge Levels on Comprehension of Speed Simulation, Cognitive Load, and Learning Efficiency for Fifth Grade Elementary Students[1]

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ABSTRACT

The purpose of this study was to investigate how cognitive load reduction strategies and learners' prior knowledge affect on comprehension of speed simulation, cognitive load, and learning efficiency. It was randomly sampled 77 participants among fifth grade students of an elementary school in Seoul city, Korea. They were divided into two groups of prior knowledge (higher and lower) by two different treatment groups (visual worked-example simulation group, visual-auditory worked-example simulation group). Dependent variables were comprehension of speed simulation, cognitive load, and learning efficiency. Results showed that visual-auditory worked-example simulation group was more efficient on comprehension of speed simulation than visual worked-example simulation group, regardless of learners prior knowledge level, so that less cognitive load led to higher level of comprehension.

Key words: cognitive load, cognitive load reduction strategy, prior knowledge, learning efficiency

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Ⅰ. Introduction

Cognitive load theory is a kind of instructional theory that starts from the idea that human working memory is limited with respect to the amount of information it can hold and the number of operations it can perform on that information (Van Gerven, Paas, Jeroven, Van Merrinboer, Hendriks, & Schmidt, 2003). When new information is presented to learners, inexperienced learners generally experience an increased cognitive load (Kalyuga, Chandler, & Sweller, 1999; Sweller, 1994). As this kind of heavy cognitive load works negatively on the mental process to acquire the new information, instructional strategies are needed to facilitate schema construction and automation by reducing working memory load (Van Gog, Ericsson, Rikers, & Paas, 2005). Cognitive load theory describes the different sources of working memory load, related to the complexity of the material (intrinsic cognitive load), the instructional design (extraneous cognitive load), and the amount of mental effort learners invest in learning the materials (germane cognitive load) (Wallen, Plass, & Brucken, 2005).

Worked-example simulation is regarded as one of the efficient strategy for reducing extraneous cognitive load because its systematic structure can reduce unnecessary cognitive load arising from inquiry learning, exploratory learning, and problem-solving learning. Such worked-example simulations can be categorized as visual worked-example simulation and visual-auditory worked-example simulation.

Strategy for reducing extraneous cognitive load such as visual-auditory worked-example simulation which can present visual information with auditory information together, is a typical strategy for reducing extraneous cognitive load (Chandler & Sweller, 1991, 1992, 1996; Ward & Sweller, 1990). This simulation is based on two features of working memory suggested by Baddeley (1986, 1998) that working memory has a limited capacity and may be divided into visual spatial sketchpad and phonological loop. The division of working memory into a visual channel and auditory channel suggests that cognitive load can be reduced when information is divided into visual information and auditory information. Mayer (2001), as a similar viewpoint, suggests dual-channel where visual information and auditory information are processed separately.

Some researchers (e.g. Chandler & Sweller, 1991, 1992, 1996) showed that the simultaneous provision of visual and verbal information was effective. On the other hand, Craig, Gholson, and Driscoll (2002) insisted that provision of a single type of information according to the prior knowledge level of learners could be more effective. In this way, instructional techniques that are highly effective with inexperienced learners can lose their efficiency and even have negative consequences when used with more experienced learners (Kalyuga, Ayres, Chandler, & Sweller, 2003). Considering that there are different results for learning effects from visual and auditory worked-example simulations and visual worked-example simulations, it is necessary to examine learning efficiency according to the two strategies of methods for reducing extraneous cognitive load depending on the learner's prior knowledge level. This study proposed the following research questions:

1) What is the effects of the two strategies for reducing extraneous cognitive load and the levels of prior knowledge on comprehension of speed simulation?
2) What is the effects of the two strategies for reducing extraneous cognitive load and the levels of prior knowledge on cognitive load?
3) What is the effects of the two strategies for reducing extraneous cognitive load and the levels of prior knowledge on learning efficiency?

Ⅱ. Application of Cognitive Load Theory in Instructional Design

Extraneous cognitive load, which can be changed by improving teaching-learning strategy such as data presentation method, learning contents presentation method, and learning strategy, is regarded as the most efficient method for reducing unnecessary cognitive load (Van Merrinboer & Sweller, 2005). Extraneous cognitive load is also closely related to learners' prior knowledge level. If a learner has a sufficient working memory capacity, he/she would not experience difficulty in solving problems although there is extraneous cognitive load arising from inappropriate instructional design. In the case where a learner has insufficient capacity for working memory, then extraneous cognitive load should be low for successful performance. This suggests that a more effective teaching strategy should be devised, in which extraneous cognitive load can be properly controlled according to the learner's prior knowledge level.

Ⅲ. Effects of Visual Worked-Example Simulation and Visual-Auditory Worked-Example Simulation on Learning Outcomes

Worked-example simulation is regarded as one of the effective strategies for reducing extraneous cognitive load (Pass & Van Merrinboer, 1994; Quilici & Mayer, 1996). When solving unfamiliar problems, learners normally use a means-ends search strategy directed toward reducing differences between current problem states and goal problem states by using suitable operators. Providing worked-examples instead of problems eliminates the means-ends search and directs a learner's attention toward a problem state and its associated moves (Kalyuga, Ayres, Chandler, & Sweller, 2003). Several studies (e.g., Pass & Van Merrinboer, 1994; Quilici & Mayer, 1996) advocating worked-examples insist that those with a systematic structure are more effective as they can reduce unnecessary cognitive load arising from inquiry learning, exploratory learning, and problem-solving learning.

This worked-example simulation could be divided into two different kinds of worked example simulations: visual worked-example simulation and visual-auditory worked-example simulation. The provision of visual and auditory information simultaneously is regarded as the most common strategy to reduce extraneous cognitive load (Chandler & Sweller, 1991, 1992, 1996; Ward & Sweller, 1990). This is because simultaneous provision of visual and auditory information helps learners understand and integrate information. On the other hand, Craig, Gholson, and Driscoll (2002) insist that simultaneous provision of visual and auditory information is not always effective.

There are distinctive opinions on the respective effects of these two types of extraneous cognitive loads. Many research reports have been presented to support the assumption that simultaneous provision of visual and auditory information helps learners understand and integrate information (Chandler & Sweller, 1991, 1992, 1996; Ward & Sweller, 1990). Those studies have been based on features of working memory that have a limited capacity and are divided into visual spatial sketchpad and phonological loop (Sweller, 2003). This means that the teaching strategy which presents visual materials of pictorial as well as graphic information can present a high cognitive load to the limited memory resources of learners, and the cognitive load may be reduced when visual information and auditory information are presented separately rather than together.

More specifically, Mayer and Moreno (1998) reported that in multimedia-aided teaching programs, the simultaneous provision of visual and auditory information is more effective for reducing cognitive load than providing learning content solely through the visual mode. They compared two groups, each of which was presented with a different instructional treatment. The first group was simultaneously provided graphic information and animation about the formation of lightening. The second group was provided with verbal information in addition to the animation and graphic information. The results showed that the first group processed graphic information and animation in the visual working memory, while the second group processed graphic, pictorial and verbal information in the visual-auditory working memory. As the second group distributed the cognitive load, they demonstrated higher learning achievement. According to the findings, the authors contended that simultaneously processing visual information and verbal information resulted in a higher learning outcome.

However, some studies (e.g. Craig, Gholson, and Driscoll, 2002; Mayer, Heiser and Lonn, 2001) found that provision of either auditory or visual information was more effective for learners with a higher prior knowledge level. According to such studies, the provision of both visual and auditory information to learners who can understand the content via one mode could result in a redundancy effect, so it is desirable to provide either visual or auditory information rather than to provide both simultaneously (Van Merrinboer & Ayres, 2005).

According to Craig, Gholson, and Driscoll (2002), as well as Mayer, Heiser, and Lonn (2001), a group presented with auditory information alone was more effective than a group presented with a simulation containing both visual and auditory information. In addition, according to Kalyuga, Chandler, and Sweller (2000), simultaneous provision of diagram and auditory text was more effective at early stages, as it conducts duplicate processing in verbal and visual processing areas, thereby reducing cognitive load, but as learners got familiar with learning content, the provision of auditory information alone resulted in a higher learning outcome.

Ⅳ. Methods

A. Participants

It was randomly sampled 77 participants among fifth grade students of an elementary school in Seoul city, Korea. Students participated in a class that used a computer program with a time-distance graph as part of their regular science subject matter. They were randomly assigned to one of 4 cells in a 2×2 between-subjects factorial design. The first factor, prior knowledge, described that scores of prior knowledge test showed high (HP group) or low (LP group). Participants were assigned through a median split either to a group with high prior knowledge or a group with low prior knowledge.

The second factor, strategies for reducing extraneous cognitive load, described that only a visual worked-example simulation (VW) or a visual-auditory worked-example simulation (VAW) was presented. There were 21 participants in the HP-VW group, 17 participants in the HP-VAW group, 20 participants in the LP-VW group, 19 participants in the LP-VAW group.

There was no significant difference in the prior knowledge scores between 'visual worked-example simulation' group and 'visual-auditory worked-example simulation' group if learners had high prior knowledge ($F(1,36)=.02$, $p>.05$). In the case of students with lower prior knowledge level, there was no significant difference in the prior knowledge scores between 'visual worked-example simulation' group and 'visual-auditory worked-example simulation' group ($F(1,37)=0.76$, $p>.05$).

B. Materials and Tools

Each participant was taken the prior knowledge test, the cognitive load test, and the comprehension of speed simulation. The prior knowledge test (Cronbach α = .74) was multiple-choice, consisting of 10 items to assess learners' general knowledge about 'speed'. Students could receive maximum of 100 points, 10 for each item. This test was developed by researchers and 2 elementary school teachers.

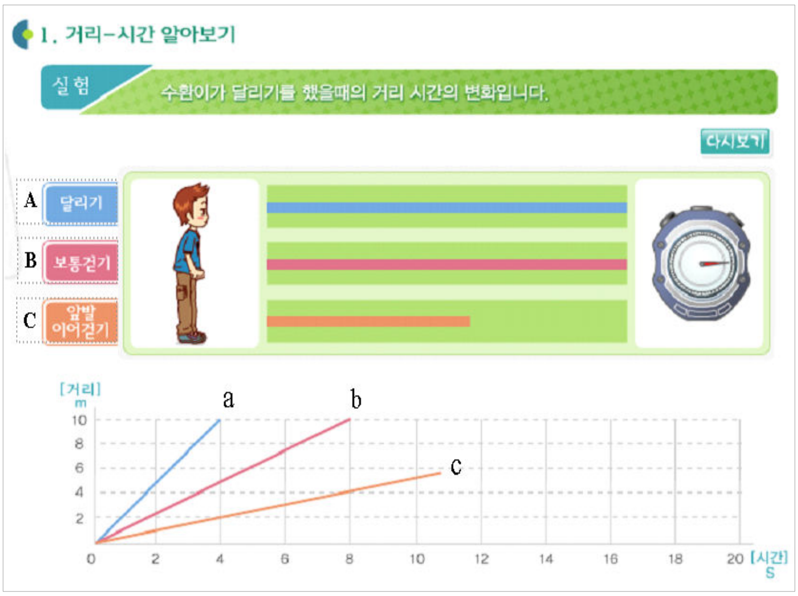
The comprehension test of speed simulation was multiple-choice, consisting of 10 items to assess learners' understanding of key concepts presented in the computer simulation of science topic in the elementary textbook. Students could receive a maximum of 100 points, 10 for each item. This test was developed by researchers and 2 elementary school teachers. The reliability coefficient of this test is Cronbach α = .85

Cognitive load (Cronbach α = .82) was measured with 9-point rating-scale developed by Pass (1992). This test was modified from the task difficulty scale perceived by learners themselves which was developed by Borg, Bratfisch, Dornic (1971). A reliability coefficient was Cronbach α = .90 (Paas, 1992), .82 (Paas & Van Merrinboer, 1994).

Learning efficiency developed by Paas and Van Merrinboer (1994) reflects the ratio between cognitive load and performance in the comprehension test of speed simulation. Paas and Van Merrinboer's (1994) procedure was followed to convert cognitive load and performance scores into efficiency scores. The learning efficiency (E) score is determined by the perpendicular distance between a dot and the diagonal E = 0, where cognitive load and performance are in balance.

Computer-based instructional materials were developed, based on computer simulation retrieved from www.scienceall.com, and redesigned by researchers. Computer based instructional materials were divided into two different kinds of simulations (e.g. visual worked-example simulation and visual-auditory worked-example simulation).

In the visual worked-example simulation, a program shows an explanation in detail through visual information. The visual worked-example simulation was a visual display of a time-distance graph showing a difference of 'speed' between a boy's running, walking, and slow walking (refer to Figure 1).



〔Figure 1〕 Screenshot of visual worked-example simulation

A screenshot of the visual worked-example simulation is shown in Figure 1. English translations of the Korean text on the screen are as follows. Upper left corner: "Studying time-distance graph 1", Second line : "Experiment: the time-distance graph is changed by the speed of a boy", 'A' box: "Running", 'B' box: "Walking", 'C' box "Slow Walking". The time(s) is shown as the x axis and the distance (m) is shown on the y axis of the graph. The 'a' line on the time-distance graph appears from the starting point together when a boy runs and the 'a' line on the right side of a boy appears. The 'b' line appears when a boy walks and the 'b' line on the right side of a boy appears. The 'c' line appears when a boy walks slowly and the 'c' line in right side of a boy appears. The speed of the 'a' line (running)'s appearance is highest and that of the 'c' line (slow walking)'s appearance is lowest. It should be noted how slopes could be different from a line on a distance-time graph, and the slope of the line determines the speed. The steeper the slope, the faster the speed.

The visual-auditory worked-example presents the same visual information as the visual worked-example simulation as shown in Figure 1. However, the visual-auditory worked-example simulation presents auditory information. In addition, there is a narration explaining the feature that the slope of the line in the time-distance graph is changed differently as a boy runs, walks, or walks slowly.

C. Procedure

This experiment was conducted in the regular classes. They spent 10 minutes completing the prior knowledge test. The assigned learning task was to use the simulations in order to determine the relationship among 'time, distance, and speed' that make up velocity. Students carefully read the instructions and were given opportunity to ask any questions. They spent about 20 minutes to use the computer simulation. After completing their work with the simulations, participants received the comprehension test of speed simulation, cognitive load test, and learning efficiency test.

D. Data Analysis

First, Differences of performance in the comprehension test of speed simulation according to the two strategies for reducing extraneous cognitive load and the levels of learner's knowledge were analyzed by two-way ANOVA with SPSS 12.0.

Second, Differences of cognitive load according to the two strategies for reducing extraneous cognitive load and the levels of learner's prior knowledge were analyzed by two-way ANOVA with SPSS 12.0.

Third, The differences in the learning efficiency score were determined by the perpendicular distance between a dot and the diagonal $E = 0$, where cognitive load and performance are in balance.

V. Results

Table 1 presents the mean scores and standard deviations for the four groups on the measure of comprehension of speed simulation and cognitive load. In order to understand how instructional strategies for reducing extraneous cognitive load and prior knowledge affected on the speed simulation comprehension scores and cognitive load scores, we conducted a two-way analysis of variance, with prior knowledge (high vs. low) and strategies for reducing extraneous cognitive load (VW vs. VAW).

Strategies Reducing Extraneous Cognitive Load	HP Group			LP Group		
	N	M	SD	N	M	SD
Results of Speed Simulation Comprehension Test						
VW	21	50.90	18.24	20	36.45	17.10
VAW	17	63.65	13.30	19	41.37	23.54
Results of Cognitive Load Test						
VW	21	4.67	1.98	20	4.65	2.11
VAW	17	3.94	1.60	19	3.58	1.67

<Table 1> Mean Scores and Standard Deviations for the VW-HP, VAW-HP, VW-LP, VAW-LP Groups on the Comprehension Test of Speed Simulation and Cognitive Load Test

Note. VW = Visual Worked-Example Simulation;
VAW = Visual-Auditory Worked-Example Simulation;
HP = High Prior Knowledge Group;
LP = Low Prior Knowledge Group

A. Results of Comprehension of Speed Simulation

Two-way ANOVA revealed main effects for prior knowledge ($F(1, 73) = 18.82$, $MSE = 342.83$, p), and for strategies reducing extraneous cognitive load ($F(1, 73)$ =

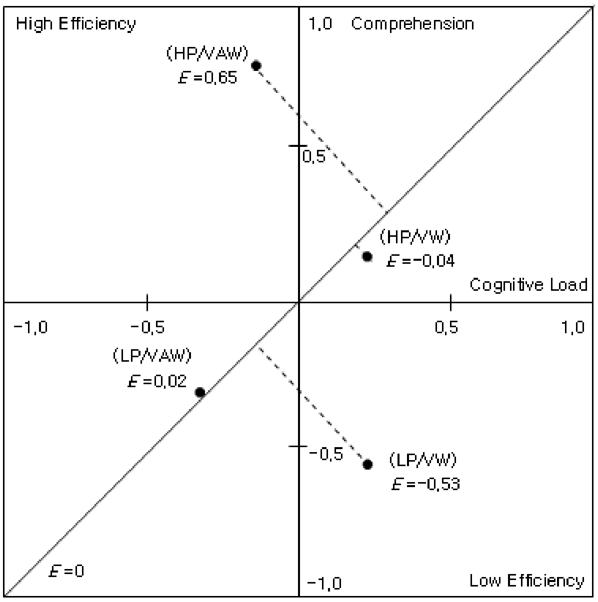
1.25,). High prior knowledge learners (M = 56.61, SD = 17.25) achieved the higher comprehension scores than low prior knowledge learners (M = 38.85, SD = 20.37), and the Visual-Auditory Worked-Example Simulation group (M = 51.89, SD = 22.21) achieved higher comprehension scores than Visual Worked-Example Simulation group (M = 43.85, SD = 18.94). The analysis did not reveal any interaction effect for prior knowledge and strategies for reducing extraneous cognitive load (F(1, 73) = .85, n.s.). Concerning the interaction effect of prior knowledge and strategies for reducing extraneous cognitive load, both learners with high prior knowledge level and learners with low prior knowledge level showed more benefits from Visual-Auditory Worked-Example Simulation than from Visual Worked-Example Simulation.

B. Results of Extraneous Cognitive Load Reduction

Two-way ANOVA revealed main effects for methods reducing extraneous cognitive load (F(1, 73) = 4.42,). There was significant difference between Visual Worked-Example Simulation (M = 4.66, SD = 2.20) and Visual-Auditory Worked-Example Simulation (M = 3.75, SD = 1.62). However, this did not reveal main effects on prior knowledge. There was no significant difference between high prior knowledge learners (M = 4.34, SD = 1.85) and low prior knowledge learners (M = 4.13, SD = 1.96). The analysis also did not reveal any interaction effect on prior knowledge and strategies for reducing extraneous cognitive load (F(1, 73) =.16, n.s.). Concerning the interaction effect of prior knowledge and strategies for reducing extraneous cognitive load, both learners with high prior knowledge level and learners with low prior knowledge level showed more benefits from Visual-Auditory Worked-Example Simulation than from Visual Worked-Example Simulation.

C. Learning Efficiency

As shown in Figure 2, learners with high prior knowledge showed the highest learning efficiency (E=0.65) in visual-auditory worked-example simulation and the lowest efficiency (E=-0.04) in visual worked-example simulation. The learners with low prior knowledge showed the highest efficiency (E=0.02) in visual-auditory worked-example simulation and the lowest efficiency (E=-0.53) in visual worked-example simulation. It was found that both learners with high prior knowledge level and low prior knowledge level were most efficient in visual-auditory worked-example simulation together (refer to Figure 2).



[Figure 2] Learning Efficiency According to Prior Knowledge Level and Cognitive Load Reduction Strategies

Note. HP = high prior knowledge level;
LP = low prior knowledge level;
VW = visual worked-example simulation;
VAW = visual-auditory worked-example simulation

Ⅵ. Discussion and Conclusion

As the volume of working memory is limited when learners study with new information, we need to develop instructional conditions and environments that can effectively overcome the limited capacity of working memory. This study aimed to find the effects of the strategies for reducing extraneous cognitive load and the level of prior knowledge on the comprehension of speed simulation, cognitive load, and learning efficiency. Results showed that a visual-auditory worked-example simulation was more efficient than a visual worked-example simulation regardless of learner's prior knowledge level.

An analysis of the comprehension scores of speed simulation according to the strategies for reducing extraneous cognitive load showed significant difference. There was a significant difference between the visual worked-example simulation and the visual-auditory worked-example simulation. This implies that visual-auditory simulation is most effective with either high prior knowledge level or low prior knowledge level. This is consistent with former researches (e.g., Chandler & Sweller, 1991, 1992, 1996; Mayer & Moreno, 1998; Ward & Sweller, 1990) that showed simultaneous presentation of visual and auditory information is a typical method to reduce extraneous cognitive load, as cognitive load could be reduced when animation and graphic representation are processed at the visual information processing area and auditory information at verbal information processing area, respectively.

Results of the interaction effect showed that all students with low and high prior knowledge benefitted from the visual-auditory worked-example simulation more than the visual worked-example simulation only. This result was consistent with the learning efficiency. All students with low and high prior knowledge level showed the highest learning efficiency in visual-auditory worked-example simulation. In other words, in the visual worked-example simulation, which presents visual information only, students with low and high prior knowledge showed lower comprehension and higher cognitive load and lower efficiency than visual-auditory worked-example simulation. This is contradictory to the result of a study that presenting two strategies for reducing extraneous cognitive load to learners with high prior knowledge could cause a redundancy effect (Van Merrinboer, & Ayres, 2005). This supports many studies (e.g., Chandler & Sweller, 1991, 1992, 1996; Ward & Sweller, 1990) that simultaneous presentation of visual information and auditory information helps learners understand and integrate information better than the presentation of single information.

According to the results in this research in which visual-auditory worked-example simulation was more efficient to all students with high or low prior knowledge level, further research in different learning environment and knowledge domains is clearly needed before any firm conclusions can be drawn.

Moreover, future research should be conducted to explore intrinsic cognitive load and germane cognitive load in relationship to cognitive load and learning efficiency. Further, learner's cognitive flexibility could be considered as a research variable to reduce the cognitive load for enhancing learning outcomes and learning efficiency.

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